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System Analysis of Shallow Land Burial

Technical Background

Prepared by D. Lester, D. Buckley, S. Donelson, V. Dura, M. Hecht, W. Horton, T. Nakai, T. Pasternak, L. Robertson, R. Stula, J. Stoddard

Science Applications, Inc.

Prepared for
U.S. Nuclear Regulatory
Commission

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Manuscript Completed: January 1981
Date Published: March 1981

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Division of Waste Management
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Washington, D.C. 20555
NRC FIN No. B6428-9

ABSTRACT

This is volume two of a three volume set detailing the activities and results of the System Analysis of Shallow Land Burial Project. Activities under four project tasks are described: Task 1 - Identify Potential Radionuclide Release Pathways, Task 2 - Systems Model for Shallow Land Burial of Low-Level Waste, Task 3 - Sensitivity and Optimization Study and Task 4 - Reference Facility Dose Assessment.

TABLE OF CONTENTS

Section Page

SUMMARY. xiii

1 INTRODUCTION TO VOLUME 2 1-1

1.1 Background 1-1
1.2 Modeling Approach. 1-2
1.3 Organization of Volume 2 . . . .

2 SITE DESCRIPTIONS. 2-1

2.1 Introduction 2-1
2.2 Maxey Flats. 2-2
2.3 Barnwell, South Carolina 2-3
2.4 Beatty, Nevada (Industrial/Nuclear Disposal Site 2-5
2.5 Sheffield. 2-7
2.6 Richland/Hanford 2-8
2.7 West Valley. 2-10

3 DOSE PATHWAYS - GENERAL DISCUSSION 3-1

4 NUCLIDE SOURCE TERMS 4-1

4.1 General. 4-1
4.2 Fuel Cycle Wastes. 4-2
4.3 Non-Fuel Cycle Wastes. 4-8
4.4 Estimated Radionuclide Concentrations in Low-Level Waste. 4-9
4.5 Release Fractions (Source Term Data Base). 4-17

5 RADIONUCLIDE RELEASE SCENARIOS 5-1

5.1 Radionuclide Pathways. 5-1
5.2 Development of Scenarios 5-41

6 MODEL DESCRIPTION. 6-1

6.1 Overview 6-1
6.2 Executive Program (EXEC) 6-2
6.3 Aquifer Transport Subprogram (AQIOFR). 6-2
6.4 Atmospheric Transport Subprogram (ATMOS) 6-10
6.5 EROSIO 6-20
6.6 Unsaturated Zone Transport Subprogram. 6-33

Section Page

6.7 Direct Exposure Model (DIRECT). 6-47
6.8 The Population Doset Subprogram (DOSET) . . . 6-53
6.9 Data Sorting Subroutine (PREDOS). 6-71

7 SENSITIVITY STUDIES 7-1

7.1 Introduction. 7-1
7.2 Methodology 7-1
7.3 Independent Variables 7-2
7.4 Experimental Design 7-17
7.5 Results and Discussion. 7-37
7.6 Conclusions 7-56

8 REFERENCE FACILITY DOSE ASSESSMENT. 8-1

8.1 Introduction. 8-1
8.2 Reference Sites 8-3
8.3 Results 8-14

9 REFERENCES. 9-1

LIST OF FIGURES

Figure		Page
3-1	Comprehensive Pathways Model.	3-2
3-2	External Exposure Pathways.	3-4
3-3	Internal Exposure Pathways.	3-4
4-1	Projected Waste Volume Increases in Institutional Survey Population. (Andersen, et al. 1976).	4-10
5-1	Low-Level Waste Burial Operations	5-2
5-2	Low-Level Waste Burial Site Operations.	5-4
5-3	Schematic of Typical Combustion System.	5-11
5-4	System Flowsheet for the Bitumen Immobilization Facility.	5-16
5-5	System Flowsheet for the Cement Immobilization Facility.	5-17
5-6	Pathways of Radionuclides to the Environment from LLW Packaging and Handling Operations	5-19
5-7	Low-Level Waste Management Activity Phases.	5-43
5-8	Equivalenence of Event Trees and Event Tables . . .	5-45
5-9	Variables Included in LLW Release Scenarios	5-46
5-10	Low-Level Waste Burial Operations	5-48
5-11	Low-Level Waste Burial Site Operations.	5-50
6-1	Shallow Land Burial System Model Executive Program	6-4
6-2	A Typical Terminal Session in the Conversational Mode. The Underlined Data is User Supplied	6-5
6-3	Subporgram ATMOS Flow Diagram	6-19
6-4	Geometry Used to Find the Prevailing Wind Erosion Direction	6-25
6-5	Geometry Used to Compute Unsheltered Travel Distance.	6-27
6-6	UNSAT General Flow Chart.	6-35
6-7	Sketch of Head versus Moisture Content for Soil . .	6-41
6-8	Subprogram DIRECT Flow Diagram.	6-48
6-9	Flow Diagram for Subroutine DOSE.	6-69

LIST OF TABLES

Table — Page

1 Summary of Demonstration Cases (Population 41,000) . . . xiii

4-1 Projected Low-Level Waste Activity for 1979 (Curies) . . . 4-3

4-2 Projected Low-Level Waste Volume for 1979 . . . 4-4

4-3 Low-Level Liquid Wastes Collected at Power Reactors . . . 4-5

4-4 Estimated Institutional Radionuclides Shipped for Commercial Shallow Land Burial in 1975 (Activities in mCi)(Andersen *et al*. 1976) . . . 4-11

4-5 Estimated Institutional Activity Concentrations of Wastes Shipped for Burial (Andersen *et al*. 1976)(mCi/m^3) . . . 4-12

4-6 Estimated Radionuclide Cocnetrations in Low-Level Waste . . . 4-13

4-7 Other Potential Radionuclides in Low-Level Waste Not in Table 3.6 . . . 4-15

4-8 Summary of Representative Release Fractions . . . 4-18

5-1 Chemical Solidification Systems for LLW . . . 5-14

5-2 Secondary Radioactive Waste Estimated to be Generated at the BIF and CIF . . . 5-20

5-3 Radionuclide Release and Transport Mechanisms Due to Transportation of Waste . . . 5-28

5-4 Radionuclide Release Paths - Burial Operations . . . 5-29

5-5 Ranges of Values of Selected Properties of Trench Water Samples from Maxey Flats, Kentucky, Disposal Site, 1977 (Robertson 1979) . . . 5-31

5-6 Occupational Exposure at Barnwell, 1978 (Ebenback 1979) . . . 5-33

5-7 Reference Site Subpathway Leading to Inhalation or Ingestion . . . 5-42

Table		Page
6-1	Plume Width Standard Deviations (from XOQDOQ). . .	6-13
7-1	Key Variables Used in the Shallow Land Burial System Model	7-3
7-2	Variable Sets Used in Sensitivity Testing.	7-5
7-3	Levels Used in Air Path Sensitivity.	7-7
7-4	Levels Used in Water Path Sensitivity.	7-13
7-5	Constant Values for Sensitivity Studies.	7-16
7-6	1/9 Replicate of 3^6 Factorial Design	7-19
7-7	1/8 Replicate of a 2^6 Factorial Design	7-22
7-8	Air Path Sensitivity Study Variable Definitions.	7-23
7-9	Sample Blocks for 1/9 Replicate of 3^6 Factorial. .	7-24
7-19	Sample Blocks for 1/8 Replicate of 2^6 Factorial. .	7-27
7-11	Air Path Sensitivity Study Cases	7-28
7-12	1/3 Replicate of a 3^3 Factorial Design	7-38
7-13	1/4 Replicate of a 2^5 Factorial Design	7-39
7-14	Water Path Sensitivity Study Variable Definition .	7-40
7-15	Sample Blocks for 1/3 Replicate of 3^3 Factorial. .	7-41
7-16	Sample Blocks for 1/4 Replicate of 2^6 Factorial. .	7-42
7-17	Water Path Sensitivity Study Cases	7-43
7-18	Analysis of Variance for Air Path Sensitivity Study.	7-46
7-19	Computational Formulas for Air Path ANOVA.	7-48
7-20	Analysis of Variance Results for Air Path Sensitivity Study.	7-50
7-21	Analysis of Variance for Water Path Sensitivity Study.	7-52
7-22	Computational Formulas for Water Path ANOVA. . . .	7-53
7-23	Analysis of Variance Results for Water Path Sensitivity Study.	7-55
8-1	Wind Frequency Data for Semi-Arid Site (No. 1) . .	8-4
8-2	Distribution of Population Along Prevailing Wind Path for Site Nos. 1 and 2	8-6

Table		Page
8-3	Nuclide Equilibrium Coefficients* in the Aquifer. .	8-7
8-4	Composition of the Unsaturated Zone (Vadose) Above the Water Table	8-9
8-5	Nuclide Retardation Factors in Semi_Arid Site (No. 1) Unsaturated Zone.	8-10
8-6	Wind Frequency Data for Wet Site (No. 2).	8-11
8-7	Nuclide Retardation Factors in Wet Site (No. 2) Unsaturated	8-13
8-8	Summary of Cases Studied, Population: 41,000 . . .	8-16

SUMMARY

This report volume details the activities and results of the System Analysis of Shallow Land Burial Project. Activities under four project tasks are described: Task 1 - Identify Potential Radionuclide Release Pathways, Task 2 - Systems Model for Shallow Land Burial of Low-level Waste, Task 3 - Sensitivity and Optimization Study and Task 4 - Reference Facility Dose Assessment.

Early in the project, information was gathered concerning burial sites, waste packaging and transportation. This was done through literature review, telephone conversations, and visits to various sites by study teams. Sites were classified into two categories: (1) wet sites characterized by high rainfall, nearby bodies of water, and a watertable near the surface, and (2) arid sites with very low ground moisture content due to very low rainfall and high evaporation, wind erosion and very deep aquifers (more than 100 meters).

Pathways result from two main categories of occurrences: (1) chronic occurrences of near unity probability, and (2) natural and anthropogenic events of low probability. Packaging and processing contain both types of releases as does the burial operation. Transportation tends to involve only the second type (probabilistic). Either category of events is potentially high-probability, the chronic events tend to be low-consequence while the probablistic events tend to be of higher consequence. In either case, the risk (probability x consequence) is usually very low.

A large number of scenarios for transportation, packaging, burial operations, and post-operations phases was identified. For each scenario a data base is supplied which includes nuclide inventory, release fraction, and the pathway sequence. Since pathway sequence is input from the data base, any additional scenarios can be easily added to the model. The scenarios in the data base are developed from detailed event tree analysis similar to the approach used in WASH-1400.

The system model consists of a number of transport and the dose subprograms for one-dimensional unsaturated zone water seepage (UNSAT), saturated aquifer transport (AQUIFR), atmosphere transport (ATMOS), a wind erosion

(EROSIO), and dose assessment (DOSET). Other subprograms handle input/output data base manipulation and subprogram interfacing. The model is run by a main driver executive program (EXEC) which interfaces the appropriate subprograms. Data input to the Systems Model is handled through a number of data packages for weather, surface geology, sub-surface geology, and demography. The user can use standard data sets or substitute site specific data when desirable. Output of the Systems Model is annual dose commitment by nuclide, organ group, age group, pathways, and various aggregate totals. This report gives overviews and detailed description of the model and its components.

In the sensitivity study, a large number of independent variables were grouped to reduce the total number of inputs to the sensitivity testing. While this reduces the resolution, an attempt was made to group things that naturally track together, such as wind and dryness, soil size and loft percent, cows per acre, and beef cattle per acre, and so forth. Other values were held constant when it was clear that the output would be proportional to those values (for example, total population). The result was a set of 16 variable groups. Using standard fractional factorial techniques and Analysis of Variance, a test matrix of 648 air path and 144 water path cases was used in the systems model and analyzed for main effects and significant interactions. Interactions represent significant effects observed for one variable at a high or low level of the other.

Some variables were found to act like switches in the model. At one level, they would reduce doses to zero while at a slightly different level would result in measurable results. These were adjusted to "turn on" the problem. In a range where such variables "turned-on" the problem, the effect of their value was insignificant. In the water path switch-like variables were rainfall, aquifer K_d, aquifer water travel time (length divided by flowrate), soil column K_d and nuclide sollubility. In the air path switch-like variables were rainfall, nuclide solubility, site wind resistance (shelter and field angle to wind) and soil column K_d.

Some variables showed insensitivity. In the air path the layering of the soild column was found to be insignificant indicating that the geology of the soil column may not need to be defined in great detail but rather averaged properties could be used. Total colummn depth causes a pure delay in the output (with nuclide decay superimposed). The population distribution in distance was also relatively insignificant. That is, closeness to the site had little effect

Table 1. Summary of Demonstration Cases (Population 41,000).

No.	Description	Cumulative Dose (man-rem)	Direct Shine (rem)
1	Release from 100 ft incinerator stack with filtering, 560 hrs, Site No. 1 wind	2.4×10^4	
2	Release from 100 ft incinerator stack, no filtering, 1 hr, Site No. 1 wind	7.8×10^4	
3	Release from $1m^3$ of waste for 2 min, Site No. 1 wind (Inspection of packages)	6.6×10^{-6}	
4	Exposure to high intensity load at 3m for 2 min with ¼" steel shield (3000 Ci, Co-60)		7
5	Chronic exposure to a person 10m from $2100m^3$ of uncovered trench 2 min, 1/16" Aluminum shielding equipment		7.3×10^{-8}
6	Routine wind erosion Site No. 1, 10 yrs	0	
7	Routine wind erosion Site No. 2, 10 yrs	0	
8	Routine water seepage Site No. 1, 10 yrs	0	
9	Routine water seepage Site No. 2, 10 yrs	0	
10	Truck accident/fire, $90m^3$ of LWR operations waste, 30 min exposure Site #1 wind	120	1.42×10^{-4}

for airborne transport. In the water path dispersion in the aquifer had little effect on the results. Since dispersion coefficients are difficult to determine, this is fortuitous.

Significant variables of note included weather pattern (dryness, wetness, wind velocity) agriculture in the air path, nuclide quantity in the water path (held constant in the air path), and stack height in the air path.

Interactions in the air path included weather (wind and rain) with cap erodibility (geometry of cap), soil size with burial depth, soil size with site wind resistance, burial depth with site wind resistance, and burial depth with soil column retardation factor.

Water path sensitivity interactions were aquifer water travel time with nuclide solubility, aquifer water travel time with water body turnover flowrate and nuclide solubility with water body turnover flowrate. The interactions of solubility with travel time or water body turnover are very significant. It means that reasonable site resistance precludes any need to know solubility (nuclides could just as well be in solution) or also that high dilution rates in a water body destroys signficance of solubility. Perhaps, the need for better understanding of solubility is not always as necessary as might appear.

Ten cases were studied in the Reference Facility Dose Assessment. These included two incinerator stack releases, two routine on-site exposures, one high intensity load incident, wind/water chronic pathways for two sites and a major truck accident. Two sites were used to obtain comparison for a semi-arid site (No. 1) and a wet site (No. 2). The semi-arid site was patterned after the Hanford and Idaho Falls locations while the wet site was patterned after the Savannah River Plant (SRP). Detailed descriptions of the sites are given in Section 3 of this report.

Table 1 summarizes the cases studied and results obtained.

Using realistic meteorological and hydrological data, no dose from routine releases to air and water paths could be calculated since concentrations were too small. Detailed nuclide soil concentrations are given for one case to illustrate the binding of nuclides to the soil and decay of many nuclides as they are held-up due to sorption in the unsaturated zone (vadose) or aquifer.

1. INTRODUCTION TO VOLUME 2

This volume of the final report "Systems Model for Shallow Land Burial of Low-Level Waste" is intended to provide detailed technical information pertaining to development and implementation of the systems model. Volume 1 is a user manual containing sufficient information to run problems in the model assuming an active version is available to the user. Volume 3 is an appendix containing backup data for Volumes 1 and 2.

The information in this volume includes the technical detail on the model content and its development. Background information on the various phases of the project is detailed. The contents are essentially a compilation of individual task reports issued as drafts during the course of the project to develop the model.

1.1 BACKGROUND

This report is the culmination of a 15-month project sponsored by the Nuclear Regulatory Commission to develop a system model for assessment of population dose from shallow land burial disposal activities. The objective was to develop a relatively simple model which would facilitate development of licensing criteria by allowing comparison of relative merits of procedural and siting alternatives. The model is intended to be a tool for comparison as opposed to a comprehensive risk model. All phases of the system are considered: packaging, transportation, burial and post-burial. It will be integrated with other analytic capabilities at NRC for licensing support analysis.

The project was carried out in four steps marked by four district task areas. First, information was developed from literature and site visits to develop a detailed description of all possible events and chronic release mechanisms which could be identified. This comprehensive pathways list formed the basis for developing a catalog of scenarios resulting in a variety of initiating events and long-term releases. The catalog was developed using event tree analysis coupled with engineering judgement to consolidate sequences resulting in the same basic type of release. Some sequences were considered to have small probability and/or very small consequences and were deleted. The results of this activity was a list of scenarios with source terms describing a representative catalog of releases to geosphere and biosphere pathways. These are the driving forces that are then carried through geosphere/biosphere attenuators and interpreted as dose to the population. The second step was to develop the transport and dose model to perform the calculations. Existing models were surveyed and gathered. Necessary modifications were made and the various sub-models were integrated into one code for dose assessment. Then in a third step a sensitivity study was performed to determine the importance of certain variables and variable groups including main affects and, in some, cases interaction. A series of 792 runs were made as a fractional factorial design of variable groups. The fourth step was to perform demonstration test runs for selected scenarios using reference sites. A series of ten cases were studied in a wet reference site and semi-arid reference site. These cases are described in this report in detail and are provided in Volume 1 as test cases for code checking.

1.2 MODELING APPROACH

In choosing and adapting existing models the principal guidance criteria were:

- Availability (quantity and quality) of data.
- Convenience of existing model application (e.g., machine compatibility, running time, core storage, etc.).
- Verification/validation means available.
- Compatibility with other subprograms.
- Compatibility with objectives and scope of this project.

Emphasis in choosing models was on "sufficient" rather than "best". The search for the "best" model involves extensive search and exhaustive comparison of which many models may do the job needed. A sufficient model needs only to meet the basic requirements and be reasonably efficient.

The availability of data is a large concern. Many existing models far exceed data availability and their complexity is wasted since many features are not used. Models used in this study were chosen to maximize use of available data and avoid featues which could not be used at present or in the forseeable future because of lack of data. The type of data that would be supplied with license applications was visualized in formulating opinions on suitability of various models.

Flexibility was an important consideration in the system model development. Modularization of subprograms and data have been employed to allow future changes and program trouble-shooting. The subprogram sequencing is done by a data base input to allow addition of any scenario so long as a source term and sequence is identified. Thus, revision of the pathways sequencing is very simple. Approaches to the individual subprograms is discussed in detail in Section 6 and supporting Appendices (Volume 3). The models used for the subprograms are generally common in the industry and well established. Some alterations in original approaches have been necessary to meet the specific needs of the Shallow-Land Burial Model.

1.3 ORGANIZATION OF VOLUME 2

This volume is organized around the results of the four steps described above. A section on site description (Section 2) provides background information that was used in developing scenarios, model features and reference sites for the demonstration phase. Section 2 also is a record of the results of literature review and site visits made by various project teams early in the project (Trip reports from the project teams are included in Volume 3 as Appendix A). Section 3 is a brief discussion of the dose pathways problem as an orientation to Sections 4, 5, and 6 which describe the details of scenario and model development. Sections 4 and 5 describe the results of the activities during the first step in the project. The method of scenario and source term development and results obtained are described. Detailed scenario and source term results are in Appendix B and C, Volume 3 and in Sections 4 and 7, Volume 1 (the user manual). Section 6 is a detailed description of the System Model itself as it was developed during the second project step. Section 7 described the third step: sensitivity studies and Section 8 describes the fourth step: reference facility dose assessment.

Data availability is also a large concern. Many existing models [illegible] and their complexity [illegible] required. Models used in this study were chosen to [illegible] use of available data and avoid [illegible] which would not be used [illegible] future because of [illegible]. The types of data [illegible] against those [illegible] [illegible] availability [illegible] consideration in the system models development [illegible] employed [illegible] future changes [illegible] hypotheses [illegible] is done by [illegible] long-term [illegible] [illegible] of the models [illegible] specific model of the shallow-land burial model.

1.3 ORGANIZATION OF VOLUME

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2. SITE DESCRIPTIONS

2.1 INTRODUCTION

In this section, exisiting commercial shallow land burial sites are described as well as the DOE site at Richland. The location, topography, climate, geology, and hydrology of these sites were studied and the descriptions were generated to focus on factors of concern with respect to nuclide release and transport. The descriptions are not intended to be in great detail. Many detailed descriptions can be found in the literature (Papodopulos and Winograd, 1974; Morton, 1968; Adam, et al, 1978). Factors relevant to development of the systems model and the release pathways are emphasized in the sections that follow.

It became apparent during the study that two basic types of sites are encountered: (1) high-rainfall, high-watertable locations where runoff, seepage, leaching, and groundwater transport are of paramount concern and (2) arid, very deep-watertable locations where only surface water (flash floods, snow melt) are of concern and airborne pathways predominate. In this study we will call these (1) "Wet" Sites and (2) "Arid" Sites. Category (1) commercial sites include Maxey Flats, Sheffield, Barnwell, and West Valley and category (2) commercial sites include Beatty and Richland. Savannah River (SRL) and Oak Ridge (ORNL) fit category (1) while DOE sites at Hanford, Los Alamos and Idaho (INEL) (with some exception) fit category (2).

2.2 MAXEY FLATS

2.2.1 Location

The low-level radioactive waste disposal site of Maxey Flats is located 16 kilometers northwest of the town of Morehead in Fleming County, northeastern Kentucky. The area of the site, which is owned by the State of Kentucky, is about 200 acres. In 1963, the Nuclear Engineering Company was issued a license by the State of Kentucky to operate the disposal facility. In 1971, it was decided that additional studies were needed at Maxey Flats to insure that precipitation which infiltrated the completed trenches would not result in contamination of the groundwater by radionuclides. In December, 1977, the disposal site was ordered shut down so that a two-year period of study on the safety factors of the waste disposal technique could ensue. Operations did not resume at the end of the two-year period.

2.2.2 Topography and Climate

The topography of the region consists of gently rolling hills and valleys. Maxey Flats is situated on top of a broad mesa. Moderately steep valleys border the Maxey Flats mesa on the eastern and southern margins. The area is drained by Rock Lick Creek.

The climate at the Maxey Flats site is humid, consisting of high rainfall and low evaporation. The mean annual precipitation amounts to about 1.1 meters per year, mostly in the form of heavy storms. There are sharp contrasts between winter and summer seasonal temperatures in the Maxey Flats region.

2.2.3 Geology and Hydrology

The stratigraphy of the Maxey Flats site consists of approximately 4.5 meters of dry, firm and moist silty clay overburden. The Bordon Formation, estimated at 20 meters in thickness, underlies the silty clay. There are two primary units in the Bordon Formation. The upper layer is the Nancy Member, about nine meters thick, consisting of alternating layers of soft, bluish-green to gray shale and hard, fine-grained, yellowish-brown sandstone. The 10.5-meter thick Farmer Member which underlies the Nancy Member is comprised of alternating layers of sandstone and vertically jointed shale. The Henley Bed, about three meters in thickness, underlies the Farmer's Member and is characterized as a greenish-gray shale layer. The upper contact of the Sudbury Shale Formation occurs at about the 27-meter depth and is identified as a moderately hard, dark green to black shale.

The uppermost watertable at the Maxey Flats site is a "perched" table located at a depth between 0.6-1.8 meters below the surface and in the soil zone above the Nancy Member. The main watertable is located at depths of 10.5-15 meters below the surface and has an erratic slope gradient. Nearly all of the water which discharges from the Maxey Flats disposal site does so by means of one of several pathways. These flow paths include surface runoff, movement through cracks and joints in the bedrock, and movement through shallow soil zones.

The radioactive waste of Maxey Flats is stored in buried trenches with dimensions of 6 meters deep, 15 meters wide, and 90 meters long. The basal unit in the trenches is the tight, impermeable Farmer Member of the Bordon Formation. The impervious nature of this layer creates a problem due to an accumulation of water which collects in the trenches, especially during periods of abundant rainfall. The excess water must then be pumped out of the trenches and processed in an evaporator facility on site.

2.3 BARNWELL, SOUTH CAROLINA

2.3.1 Location

The commercial nuclear disposal site near Barnwell, South Carolina is located about 10 kilometers west of the town of Barnwell in Barnwell County, west central South Carolina. Chem-Nuclear Systems, Inc. operates this commercial nuclear waste disposal facility on a 278-acre parcel of land which is owned by the State of South Carolina and leased to this firm for a 99-year term. The State of South Carolina and the NRC regulate the licensing requirements for the Barnwell waste disposal site.

Initially, the nuclear waste delivered to Barnwell was buried in trenches which were 6 meters deep, 15 meters wide, and 150 meters long. Presently, the facility buries the incoming waste in trenches which are much larger in size than those originally used, with dimensions equal to 6 meters by 30 meters by 305 meters. Certain high specific activity shipments of radioactive waste are buried in narrow slit trenches having dimensions of 6 meters deep, 0.8-0.9 meters wide, and 305 meters long. After the trenches are filled with nuclear waste, a shield of two to three meters of clay is placed over the trench. A vibratory compactor compresses the clay to eliminate settling. Finally, the clay is capped by a sand layer, which is contoured to prevent surface water from seeping into the trench.

2.3.2 Topography and Climate

The Barnwell area is part of the topographic region known as the Coastal Plains, an area of South Carolina characterized by gently rolling low-lying hills and flat, somewhat swampy meadows. The main river system draining the area around Barnwell is the Savannah River,which flows from northeast to southwest through wide valleys which are often bordered by swamplands.

The climate in this area is characterized as humid and subtropical with long summers and mild winters. The average annual precipitation in Barnwell County is 1.15 meters, which is a relatively high amount of rainfall.

2.3.3 Geology and Hydrology

The uppermost layer of sediment near the surface at the Barnwell site is a dense, reddish-brown clay known as the Hawthorne layer, which is approximately 1.2 meters in thickness. Underlying the Hawthorne clay is the Barnwell (sandstone) layer. In digging the waste burial trenches, the clay is removed and the trench is dug to a six-meter depth in the Barnwell sandstone.

The watertable lies relatively close to the surface at the Barnwell site in comparison to the depth to the watertable at Beatty, Nevada, for example. The depth to the watertable is about 15 to 18 meters below the surface. Between the floor of the waste trenches and the upper boundary of the watertable, the geology consists of clay with lenses of sandstone.

Due to the humid climate and the relatively shallow watertable which characterize the Barnwell waste site, radionuclides buried there are more likely to be released and to migrate downward through the sediments into the groundwater than at the arid to semi-arid waste sites in Beatty and Richland. Therefore, test wells have been placed around the edge of each completed waste trench. These wells are sunk to the base of the trench to monitor the possible existence of water. Any water collected at the base of the trench may be pumped out to avoid contact with the buried waste.

2.4 BEATTY, NEVADA (INDUSTRIAL/NUCLEAR DISPOSAL SITE)

2.4.1 Location

Nuclear Engineering Company (NECO) operates the waste disposal site located about 18 kilometers south-southeast of Beatty, Nevada, within the Amargosa Desert in Nye County. The Beatty site is licensed by the State of Nevada for the disposal of industrial waste and solid, low-level radioactive waste. Disposal of low-level radioactive wastes was begun in 1962. The wastes were buried in trenches with dimensions of 6 meters deep, 12 meters wide and 200 meters long. At the present time the waste trenches being filled are much larger in size, having dimensions of 15 meters in depth, 37 meters in width and 245 meters in length. After the trenches are filled with waste, a one to two meter thick cap of soil is placed over the trenches to protect against exposure to the nuclear waste from soil erosion, runoff, etc.

2.4.2 Topography and Climate

The area in proximity to Beatty, Nevada, is in a broad northwesterly trending valley in the Amargosa Desert. The valley is bounded by the Grapevine and Funeral Mountains on the southwest and Bare Mountain on the northeast. Average altitudes here range between 845-849 meters above sea level. To the southeast of the nuclear waste disposal site the topography is characterized by a series of ridges which contrast somewhat from the 76-meter-high smooth, sandy Big Dune located on the valley floor.

In general, the topography of the area surrounding the Beatty site is characterized by broad, flat valleys separated by rugged mountains. This is a typical landscape usually found in a basin and range province. The slope of the site is towards the southeast, ranging between 0.3 to 0.6 meters per hundred meters and providing for good drainage of the area.

Average precipitation in the Amargosa Desert near Beatty ranges between 64 to 127 mm per year. Yearly evaporation at the site averages about 2.5 meters per year which removes much of the near-surface moisture.

2.4.3 Geology and Hydrology

The surficial deposits in the Beatty area consist of poorly sorted mixtures of fine to course grained fanglomerate materials. These sediments are primarily semi-consolidated deposits of boulders, gravel, sand silt, and clay. The exact thickness of these sediments is not known, but it is estimated to be about 175 meters. Based upon a driller's log in the Beatty area, two aquifers were identified in the semi-consolidated sediments at the 99-meter to 104-meter level and at the 144-meter to 149-meter level.

The gravel and sand sediments are permeable and transmit water more readily than the clay fraction which is impermeable and transmits water very slowly or not at all. The aquifer materials identified above at 99-104 meters and 144-149 meters consist of various-sized boulder with little clays. The permeability for the aquifer materials penetrated by the well ranges from 2440-20,300 liters/day per square meter.

The bedrock geology, which underlies the 175 meters of sediments described above, presumably consists of rocks which are similar to those exposed in the mountains that surround the valley. The rocks have been classified as the Nopah Formation, Stirling Quartzite, and Bonanza King Formation of Paleozoic Tertiary age. These units consist of structurally complex sedimentary and metamorphic limestones, dolomites, and marbles which have been fractured and faulted by recent tectonic activity. Although the Beatty site is in a seismically active area which is susceptible to severe earthquakes, it is not on an active fault zone. The only significant effects of earthquakes upon water contamination by the buried waste would be those resulting from fissures in the earth which would permit the inflow of rainfall. However, the probability that an earthquake of sufficient magnitude to create fissures would occur is very remote.

The groundwater flow in the Beatty area parallels the northwesterly trend of the valley. The piezometric surface has a computed hydraulic gradient sloping about 2.7 meters per kilometer with a direction of flow down-gradient to the southeast. As stated previously, the depth to the uppermost watertable is about 99-104 meters below the surface. It is clear from the meager annual rainfall in the Beatty area and the deeply-buried watertable that the downward migration of radionuclides through the soils to the aquifer is very unlikely.

2.5 SHEFFIELD

2.5.1 Location

The low-level solid radioactive waste burial site in Bureau County, Illinois, is located about 4.8 kilometers southwest of the rural town of Sheffield in north-central Illinois. The region is a sparsely populated agricultural area.

The Sheffield waste burial facility is owned by the State of Illinois and is operated by California Nuclear, Inc. The facility, which has a site area of nearly 27 acres, started operations in 1967. Burial operations were suspended in 1977. trenches at the site have dimensions of 6 meters deep, 12 meters wide, and 150 meters long. After the trenches were filled, they were backfilled, compacted, and mounded to lessen the infiltration of precipitation and subsequent leaching of buried wastes. Monitoring wells and drains to detect any water that might collect in the trenches have been employed at Sheffield.

2.5.2 Topography

The landform around the Sheffield waste burial site consists of east-west trending rolling hills with altitudes ranging from about 235 to 275 meters. The hills slope toward the south and merge with an intermittent drainage branch of the Lawson Creek. The surface flow of the Lawson Creek occurs only during, or subsequent to, periods of rainfall. At other times, the drainage is intermittent. The Lawson Creek drains to the north into the Green River Lowland at the northern portion of the Sheffield site.

2.5.3 Climate

The Sheffield site is located in an area of humid climate with relatively high rainfall and low evaporation. The annual precipitation is about 0.9 meters of rainfall. The rainfall is scattered througout the year with most of it falling in June and the least in February.

2.5.4 Geology and Hydrology

The surficial deposits of the Sheffield site are comprised of about 15 to 18 meters of Pleistocene age, unconsolidated glacial silty-clay loess sediments on the hills in which the site is located. The sediments have relatively low permeability to percolating groundwater.

The bedrock geology of the site, which underlies the glacial sediments, consists primarily of Pennsylvanian shales. There are minor amounts of sandstone, clay, limestone, coal, and black slaty shale which are interbedded with shale. The maximum thickness of the shale bedrock in this area is about 125-150 meters. These shales are relatively impermeable at the site, so that it is unlikely that water would migrate downward from the glacial sediments above to carry radionculides to these Pennsylvanian rocks. Some mining of coal had been carried out in the vicinity of the site some time ago.

The structural picture in the vicinity of the Sheffield site is rather stable. No major faults in the bedrock geology underlying the site are known to exist. The rocks have gentle dips in an east-southeasterly direction toward the Illinois coal basin.

Studies have indicated that a "perched" water body occurs in the glacial sediments which overlie the impermeable shale bedrock at the Sheffield site. This would appear to be the water body of main concern in the disposal of radioactive waste in the trenches.

In the hills of the southwestern and east-central parts of the site, the depth to the watertable is about 12 to 18 meters below the land surface. The groundwater gradient slopes northward over much of the site, however, so that the watertable appears to be within 7.5 meters of the land surface in the northeastern part of the site.

2.6 RICHLAND/HANFORD

2.6.1 Location

The commercial radioactive waste burial facility near Richland, Washington was opened in 1962. It is a 100-acre site which is located about 40 kilometers North of Richland in Benton County, southcentral Washington. The commercial Richland waste site is operated by the Nuclear Engineering Company

(NECO) and licensed by the State of Washington. The Hanford-DOE low-level radioactive waste burial site is located in the 200 Area of the Hanford Reservation and is only several kilometers from the commercial NECO burial site.

The waste trenches at the commercial Richland site are straight-walled trenches with dimensions of 7.5 meters deep, 24 meters wide, and 137 meters long. It requires about six to eight weeks to dig a trench of this magnitude. After the trench has been filled with wastes, 2.5 meters of fill is placed over the waste as a trench cap.

2.6.2 Topography and Climate

The Richland waste burial sites are located within the Columbia Plateau physiographic region of central Washington. The area is characterized by moderate elevations, flat plateaus, gentle slopes, and rolling hills. To the northwest of Richland lies the Rattlesnake Hills, while the Horse Heaven Hills lie to the southwest of Richland. The area is drained by the Columbia River, the Snake River, and the Yakima River.

The climate of the Richland area could be classified as arid. The annual precipitation ranges between 150-200 mm. Dust storms may occur in parts of Eastern Washington in the windier months, when the light surface of the soil is dry.

2.6.3 Geology and Hydrology

The surface material at the Richland sites is a silty sand, gravel, and clay mixture. The soil at the surface has the appearance of a beach sand. The sandy horizon extends from the surface to depths of between 45 to 91 meters. The bedrock which underlies the sediments and forms the hills around Richland consists of the Columbia River Basalts.

The depth to the watertable at the NECO and DOE (200 Areas) sites is between 70 and 110 meters below the surface of the soil. Due to the arid climate, the meager amount of rainfall, and the depth to the groundwater, no water collects in the trenches. Migration of the radionuclides from the buried waste to the hydrosphere appears to be an unlikely concern at the Richland radioactive waste burial sites.

2.7 WEST VALLEY

2.7.1 Location

The Western New York Nuclear Services Center is a low-level radioactive waste burial facility located at West Valley in Cattaraugus County, New York. This site, which began operations in 1963, was run by Nuclear Fuel Services, Inc. and licensed by the State of New York. The low-level radioactive waste on the over ten acre West Valley site was buried in trenches whose dimensions are 6 meters deep, 10.5 meters wide, and 214 meters long.

2.7.2 Topography and Climate

The West Valley site, which lies at an approximate elevation of 460 meters, is located within the physiographic area of the Appalachian Plateau. The topography consists of rounded ridges and hills which are cut by steep-sided ravines. There are several rivers and tributaries which are associated with the Appalachian Plateau province in the area near West Valley, including the Allegheny River, the Genesse River, and Cattaraugus Creek.

The climate around the West Valley site is humid with about one meter of precipitation annually. Most of the rain falls in the period from May through September. Average summer temperatures are about 18°C, while mean winter temperatures are 2°C.

2.7.3 Geology and Hydrology

The burial medium into which the waste burial trenches have been dug at the West Valley site is believed to be a lake deposit which has been reworked by glaciation. The soil consists of glacial till horizons ranging from 7.5 to 52 meters in depth. The till has very low permeability, is gray in color, and consists of a dense mixture of clay, silt, sand, and gravel. Vertical shrinkage cracks in the till horizons have been observed in the upper 4.5 meters of soil.

Below the glacial till lies Paleozoic shale and sandstone bedrock. The shales have been shown to be largely impermeable and they extend to more than 600 meters in depth.

The faulting activity nearest to the site is about 48 kilometers east in the north-south trending Clarendon-Lindon fault. However, the fault appears to have been inactive for over 350 million years. The natural seismicity in Western New York is known to be low to moderate.

The depth to the watertable at West Valley is variable and slopes with the surface drainage. Due to the low permeability of the glacial till soil into which the trenches are dug and to the high amount of rainfall that characterizes the climate of West Valley, it is possible for rain to percolate downward into the trenches. The leaching of radionuclides into the groundwater is prevented by certain operational procedures. The moisture content in the floor of the waste trenches is monitored and the water is pumped out as it collects in order to prevent the migration of radionuclides from the buried waste to the watertable.

The faulting activity nearest to the site is about 30 kilometers east in the north-south trending Clarendon-Linden fault. However, the fault appears to have been inactive for over 100 million years. The natural seismicity in western New York is known to be low to moderate.

3. DOSE PATHWAYS - GENERAL DISCUSSION

The main objective of the burial of low-level waste at shallow land burial sites is to isolate the waste from the biosphere and prevent the exposure of the population to this waste. Generally, such isolation is not total and specific segments of the population may be exposed to the waste during the collecting, transporting, processing, and burying of the waste. It is also possible that release of radionuclides from the waste after burial may take place. Such releases could conceivably result in release to the biosphere. For these reasons, it is necessary to determine what pathways to humans exist and to determine the significance of the pathways. Task 1 has as an objective the compilation of an exhaustive list of possible pathways to humans from all phases of the shallow land burial process. This section presents an overview of pathways to humans in a general discussion so that individual pathways identified can be placed in perspective

Figure 3-1 illustrates a comprehensive pathways model. The model is general since the event source is not defined. The event source can represent varied events such as transportation accidents, burial accidents, and simply normal or chronic releases. In all events, the released radionuclides need to be initially transported. This transport is generally via air or water. However, certain scenario-dependent transport mechanisms may take place, such as transport via truck tires, feet, etc. Direct gamma radiation exposure would also be covered by localized transport.

Once in the environment, a number of secondary transport mechanisms may act upon the radionuclides. The environment through which the radionuclides may be transported are air, terrestrial, and aquatic media. The terrestrial environment includes only the near-surface mechanisms. Transport via underground migration is included in the aquatic environment. As can be seen, the three media are coupled to one another via coupling mechanisms such as deposition, resuspension, and runoff.

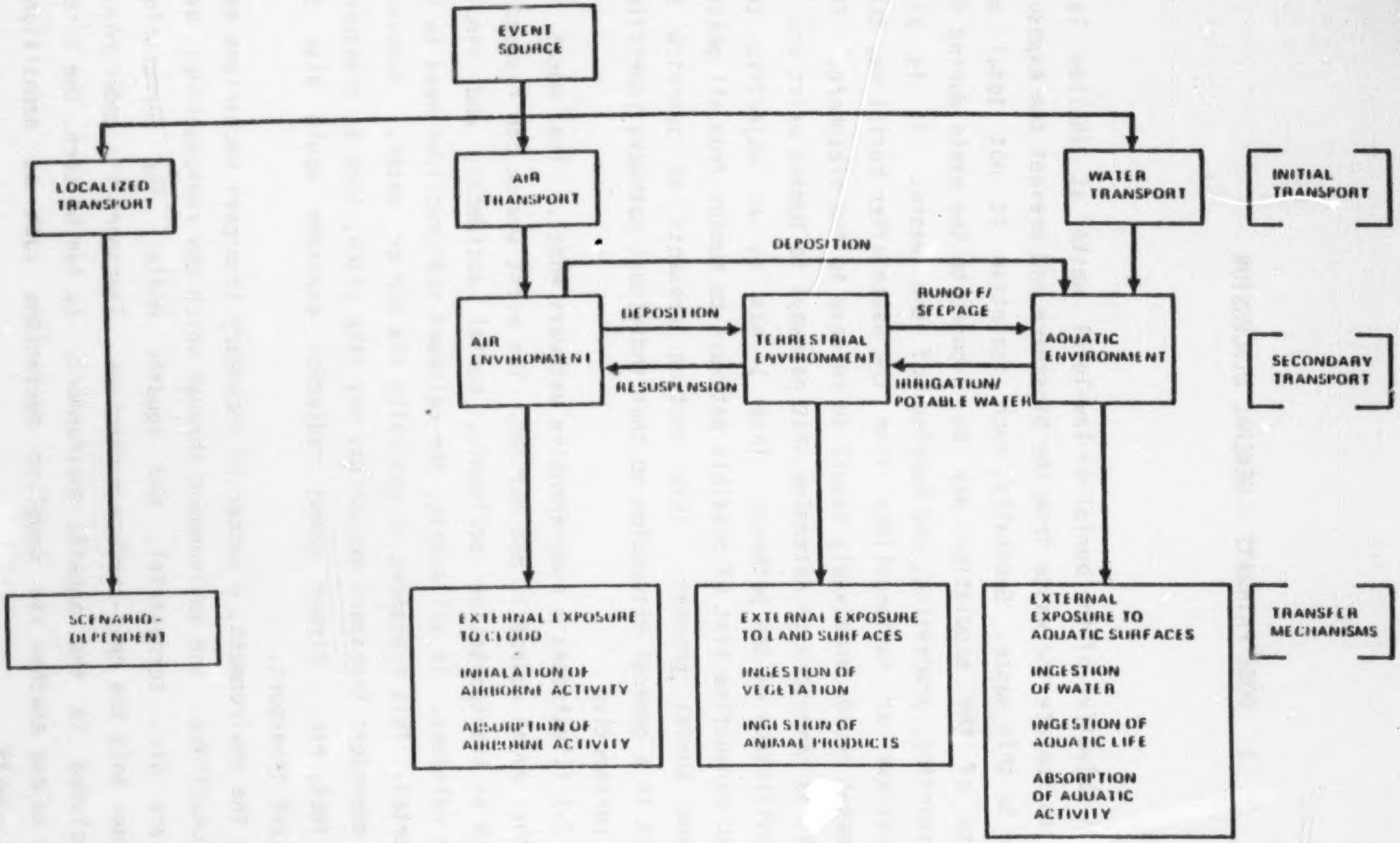

EVENT SOURCE
LOCALIZED TRANSPORT
AIR TRANSPORT
WATER TRANSPORT
INITIAL TRANSPORT
DEPOSITION
AIR ENVIRONMENT
DEPOSITION
RESUSPENSION
TERRESTRIAL ENVIRONMENT
RUNOFF/ SEEPAGE
IRRIGATION/ POTABLE WATER
AQUATIC ENVIRONMENT
SECONDARY TRANSPORT
SCENARIO-DEPENDENT
EXTERNAL EXPOSURE TO CLOUD
INHALATION OF AIRBORNE ACTIVITY
ABSORPTION OF AIRBORNE ACTIVITY
EXTERNAL EXPOSURE TO LAND SURFACES
INGESTION OF VEGETATION
INGESTION OF ANIMAL PRODUCTS
EXTERNAL EXPOSURE TO AQUATIC SURFACES
INGESTION OF WATER
INGESTION OF AQUATIC LIFE
ABSORPTION OF AQUATIC ACTIVITY
TRANSFER MECHANISMS

Figure 3-1. Comprehensive Pathways Model.

Having been transported to the biosphere, the radionuclides may expose specific segments of the population during secondary transport. These exposure possibilities are listed as transfer mechanisms in Figure 3-1. Exposure from the air environment is by either external exposure or via internal exposure due to inhalation or absorption of the radionuclides. Exposure from the terrestrial environment is by either external exposure or via food chain pathways. The aquatic environment exposures include external exposure, exposure via ingestion and absorption, and exposure via aquatic food chains. Figure 3-2 illustrates the possible external exposure pathways. Figure 3-3 illustrates the possible internal exposure pathways.

In order to classify or categorize the possible dose or exposure pathways for the shallow land burial process, it is necessary to discuss the difference between chronic and acute or discrete terminology. Pathways that are considered chronic are pathways with continuous releases such as evaporation of trench water and migration of radionuclides away from the trenches. Discrete pathways include anthropogenic events such as transportation accidents and natural events such as floods, tornadoes, and earthquakes.

Discrete events or pathways are best described using a fault-tree-type approach. These events are probabilistic in nature and, therefore, have a probability associated with their occurrence. Their relative importance can be determined by considering the resulting consequences such as health effects times the probability of occurrence. The resulting calculation is essentially the risk associated with the discrete event. Chronic pathways, on the other hand, can be considered to have a probability of unity or near unity. Therefore, while discrete events or pathways occur rarely, chronic pathways are present for greater periods of time. Of course, because of the existance of radioactive decay, chronic pathways generally diminish in magnitude of consequences over a period of time.

Also important to the classification or categorization of pathways for shallow land burial are the various processes in the system. Exposure pathways may occur during all the processes including packaging, handling, transportation, burial, and maintenance of the site. It is anticipated that the chronic pathways for all processes up to and including the burial and covering of the waste would be mainly external exposure due to proximity to the waste and possibly some inhalation of radionuclides due to leakage.

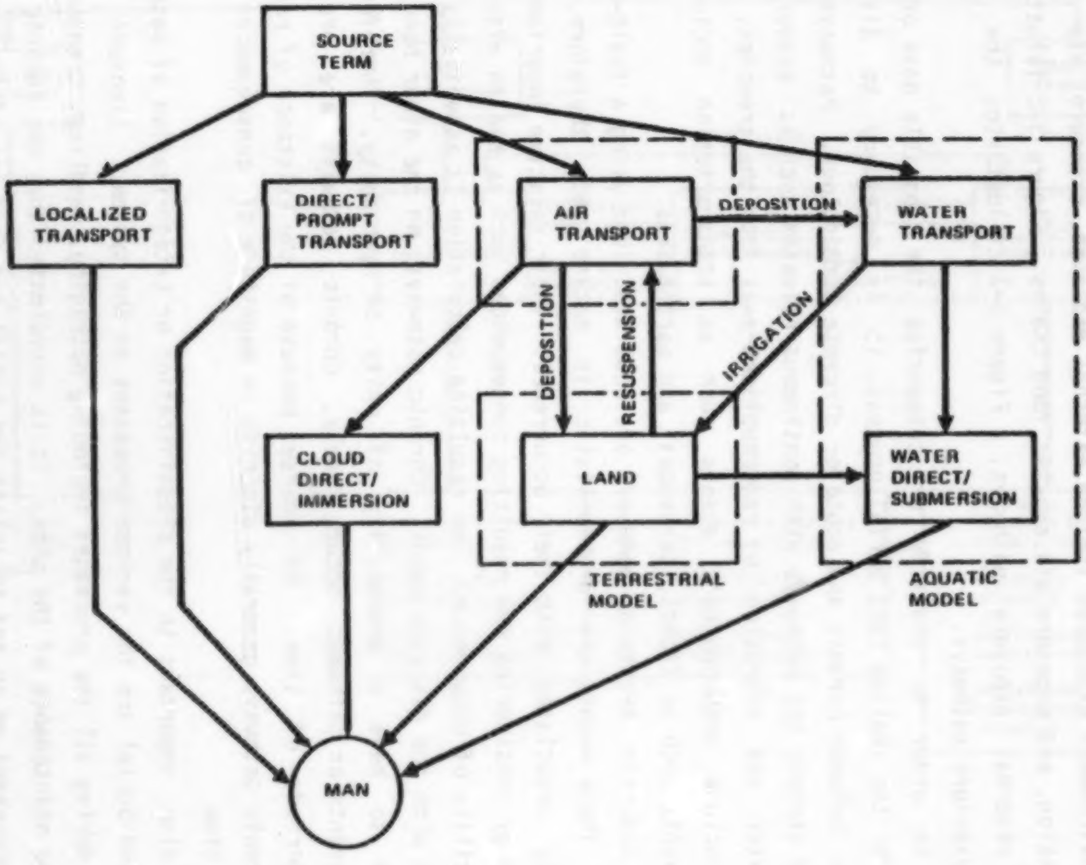

SOURCE TERM
LOCALIZED TRANSPORT
DIRECT/ PROMPT TRANSPORT
AIR TRANSPORT
DEPOSITION
WATER TRANSPORT
DEPOSITION
RESUSPENSION
IRRIGATION
CLOUD DIRECT/ IMMERSION
LAND
WATER DIRECT/ SUBMERSION
TERRESTRIAL MODEL
AQUATIC MODEL
MAN

Figure 3-2. External Exposure Pathways.

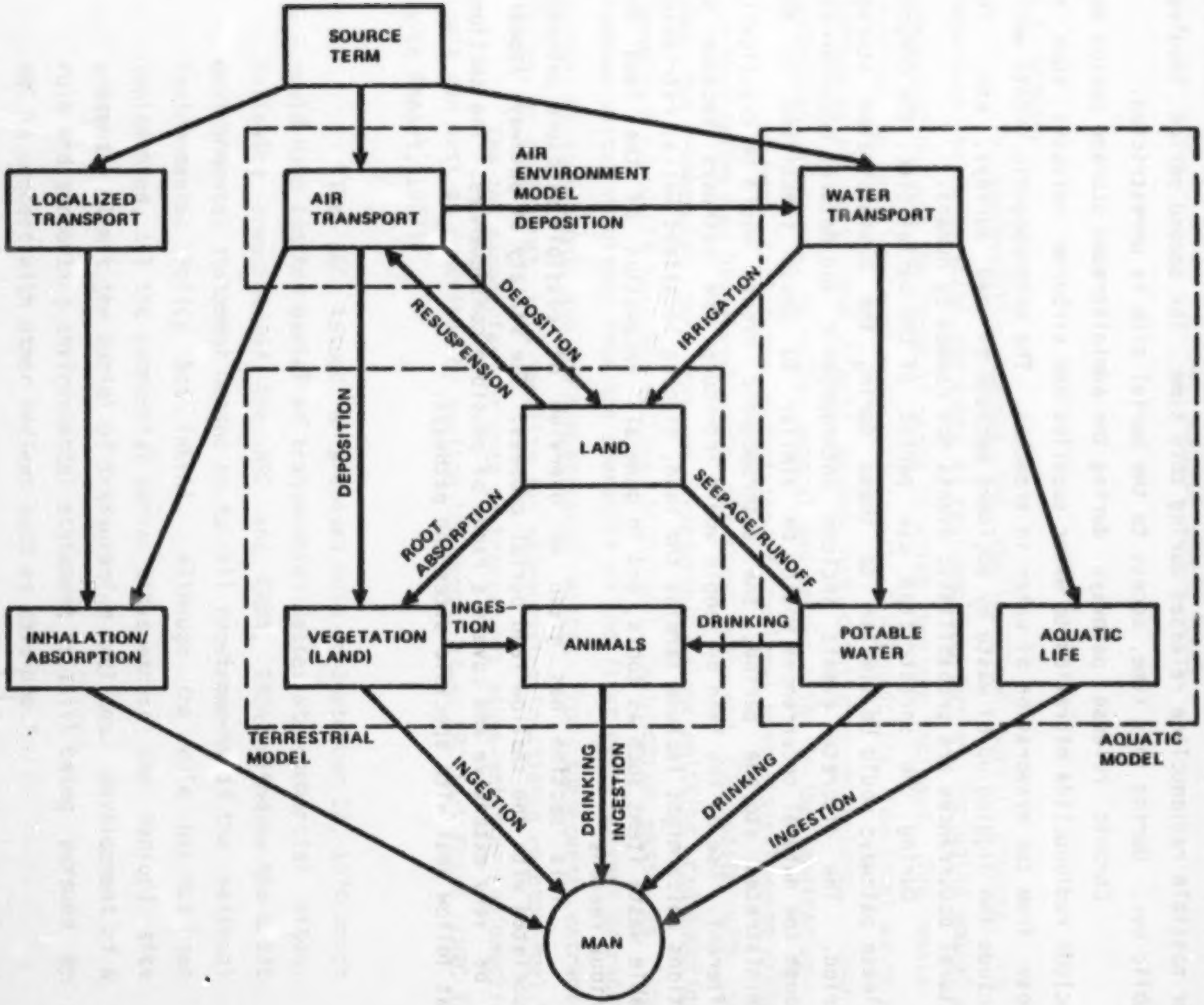

SOURCE TERM
LOCALIZED TRANSPORT
AIR TRANSPORT
AIR ENVIRONMENT MODEL
DEPOSITION
WATER TRANSPORT
RESUSPENSION
DEPOSITION
IRRIGATION
DEPOSITION
LAND
ROOT ABSORPTION
SEEPAGE/RUNOFF
INHALATION/ ABSORPTION
VEGETATION (LAND)
INGES- TION
ANIMALS
DRINKING
POTABLE WATER
AQUATIC LIFE
TERRESTRIAL MODEL
AQUATIC MODEL
INGESTION
DRINKING
INGESTION
DRINKING
INGESTION
MAN

Figure 3-3. Internal Exposure Pathways.

After the waste has been buried and covered, two time periods are assumed to follow. The first time period is an administrated storage period during which access to the burial site is controlled. The site will be monitored for possible radionuclide releases during this time. The second period involves public use. During this time, access to the burial site is unrestricted.

Chronic release pathways during the administrated storage period may include radionuclide migration to water supplies and airborne releases such as those from the evaporation of water in trenches. The anthropogenic events would include the digging up of waste by accident because of bad surveys, etc. The natural occurrences are probabilistic events not caused by humans.

During the unrestricted use period of the burial site, the chronic release pathways would be similar to those during the administrated storage period. The discrete events include anthropogenic and natural occurrences. Though the natural occurrences would be similar to those identified in the administrated storage period, the anthropogenic events would be drastically different. Use of the land by people would introduce new pathways because of actions which might include farming the land, digging localized wells, retrieving usable waste items such as tools, and in general, excavation of the land for various reasons.

This section has given an overview of possible exposure pathways associated with the shallow land burial process. The variety of pathways appears to be very extensive and covers a range of possible consequences. The sections that follow deal with specific sites and pathways.

4. NUCLIDE SOURCE TERMS

4.1 GENERAL

To successfully analyze the shallow land burial process, it is important to understand the types of radionuclides buried, including amount and concentration, and the forms of waste in which they are included. The waste is referred to as "low-level radioactive waste." Historically, low-level waste was defined as all solid and liquid wastes not considered high-level. Such a definition, of course, is rather general and leaves a lot to the imagination.

A more satisfying definition of low-level waste is all waste except: (1) that defined as high-level waste, (2) spent fuel, and (3) waste with more than ten nanocuries per gram of transuranic alpha-emitting radionuclides. Appendix F of 10 CFR Part 50 defines high-level radioactive waste as "those aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel."

The ten nanocuries per gram of transuranic alpha-emitting radionuclides limit can best be described by quoting the report of an NRC Task Force (NRC Task Force Report, 1977):

> "The AEC issued a proposed rule on September 12, 1974 which would have limited burial of transuranium wastes at commercial sites. Following creation of the NRC and ERDA, ERDA withdrew the draft environmental statement needed to fulfill requirements of the National Environmental Policy Act (NEPA). Although the rule has not been implemented, all the commercial burial sites except the Hanford site presently limit the burial of transuranium nuclides. Development of a rule and supporting environmental statement is still being pursued by NRC in concert with other reviews such as this one."

As is noted later in this report, the Hanford site will soon follow the proposed rule of ten nanocuries per gram. This was confirmed during conversations held when staff members visited that site. The expected order of importance of the major generators of commercial low-level waste is (1) nuclear reactors, (2) institutions such as hospitals, clinics, and universities, (3) industry, and (4) government laboratories. Calcium fluoride waste from fuel fabrication plants is expected to be a possible major source of waste in the future. At present, Westinghouse is disposing of this type of waste at Barnwell.

Summaries of low-level waste buried at shallow land burial sites can be found in a number of references (Holcomb, 1978, and Smith, 1979). Of most concern in this report are on the types of radionuclides that may be placed at the sites in the future. The generators can be lumped into two categories: fuel cycle facilities and non-fuel cycle facilities. The fuel cycle facilities essentially consist of nuclear reactors, particularly PWRs. The non-fuel facilities include institutions, generators of depleted and natural uranium, thorium metal fabrication wastes, government laboratories, DOE research contractors, and industry such as the radiopharmaceutical industry. It is believed about 80 percent of non-fuel cycle waste is from institutions (Andersen, et al, 1978).

Recent work by the NRC (Smith, 1979) estimated the projected low-level waste activity and volume for 1979 on the basis of 1975 - 1977 data. Table 4-1 illustrates the breakdown of the waste by activity. Table 4-2 illustrates the breakdown by volume. A more detailed discussion is presented in the following sections.

4.2 FUEL CYCLE WASTES

The majority of low-level waste is generated by fuel cycle facilities, particularly at LWRs. This type of waste includes filters/filter backwash, filtered phase-separator decant liquid, evaporator bottoms, demineralizer waste, laundry wastes, general trash, and activated components. Table 4-3 illustrates typical liquid wastes which are processed and treated as low-level waste. In general most of the activity from LWR low-level waste is in a small portion of the total volume of the waste, namely highly-activated components. Such components include control rods, fuel channels, poison curtains, etc.

In 1976, filter sludges, resins, filters, evaporator bottoms, and trash accounted for greater than 99 percent of the LWR low-level waste volume while activated components accounted for about 45 percent of the total activity. In

Table 4-1. Projected Low-Level Waste Activity for 1979.
(Curies)

FUEL CYCLE		NON-FUEL CYCLE		
		INSTITUTIONAL		OTHER
Mn-54	3.7 + 03*	H-3	6.5 + 03	Unknown
Co-58	7.3 + 03	C-14	1.1 + 02	
Co-60	3.0 + 05	Cs-137	1.0 + 02	
Cs-134	1.1 + 04	Other	2.2 + 03	
Cs-137	1.8 + 04			
Pu-239	9.4 + 00			
Pu-240				
TOTAL	3.5 + 05	TOTAL	8.9 + 03	TOTAL 4.2 + 05

*3.7 + 03 = 3.7 x 10^3

Total Estimated Volume = 9.9 + 04 m^3

Table 4-2. Projected Low-Level Waste Volume For 1979.

SOURCE OF WASTE*	% OF TOTAL
Fuel Cycle	
Dry Solids and Trash	30
Evaporation Bottoms	16
BWR Filter/Demineralizer Wastes	8
Resins	4
Miscellaneous	2
TOTAL	60
Non-Fuel Cycle	
Dry Solids and Trash	17
Liquid Scintillation Vials	15.4
Absorbed Liquids	4.2
Biowastes	3.4
TOTAL	40.0

*Excludes Calcium Fluoride Waste

Table 4-3. Low-Level Liquid Wastes Collected at Power Reactors.

REACTOR TYPE	TYPE LIQUID WASTE	SOURCE	TREATMENT
Boiling-water reactor	High purity	Equipment drains; low-conductivity back-wash water	Filtration and ion exchange
Boiling-water and pressurized water reactors	Low purity	Floor drains; water from dewatering of slurry wastes	Filtration ion exchange or evaporation
Boiling-water and pressurized water reactors	Chemical Wastes	Laboratory and nondetergent decontamination wastes; ion exchange resin regenerant solutions	Evaporation
	Detergent Wastes	Laundry wastes; detergent-type wastes from decontamination	Filtration and/or reverse osmosis or possibly evaporation
Pressurized water reactor	Miscellaneous	Floor drains, aerated systems and equipment drains, wastes from sampling and primary (boric acid) systems	Evaporation
	Secondary system wastes	Wastes from turbine building, steam-generator blow-down (except for ion-exchange regeneration)	Filtration and ion exchange

1977, activated components accounted for nearly 80 percent of the activity. It appears that activated components are easily the most significant sources of gross activity in LWR low-level waste. The breakdown of activated component activity by curies is assumed to be:

Mn-54	5 percent
Co-58	10 percent
Co-60	30 percent
Cs-134	15 percent
Cs-137	25 percent
Other	15 percent

The average specific activity for activated components was estimated to be 3000 Ci/m^3 in 1977. For, all other LWR low-level waste the estimated average was 1.3 Ci/m^3.

For comparison, if the Three Mile Island (TMI) cleanup waste from resins, filters, and sludge is between 200,000 and 500,000 curies, it is equal to about four to ten times the activity in resins, filters, sludge, and evaporator bottoms disposed of in 1977.

The estimated Pu-239 and Pu-240 activity in LWR waste in Table 4-1 was assumed to be 0.312 Ci per GWe-yr for BWRs and 0.155 Ci/GWe-yr for PWRs. The generation numbers for 1979 were 15 GWe-yr for BWRs and 30 GWe-yr for PWRs. The concentration estimates were taken from work by others. (Lapides, et al, 1978).

In generating the inventories, it was assumed that fuel cycle wastes are represented by the LWRs. These assumptions should be reviewed and updated periodically to include any significant changes. For example, in the future, calcium fluoride waste from the fuel fabrication plants could become a major waste in terms of volume.

It is convenient for the purpose of modeling to subdivide LWR wastes into (1) activated components, (2) LWR operational wastes, (3) waste from reactor decommissioning.

Highly activated LWR components represent a small volume of waste. Typically, in 1976 they comprised only about 0.04 percent of the volume, but contained some 65 percent of the total activity. These wastes include control rods, fuel channels, and other activated materials. Their volume is expected to increase in the future. Highly activated wastes are assumed to be stainless steel with cobalt-60 as the predominant element. These assumptions will need to be reviewed from time to time since, if the control rods comprise the majority of the activity, then the activation products of the neutron absorbing elements may be more significant than cobalt-60. Average specific activity of these wastes is estimated at 3000 Ci/m^3 and summarized in Volume 1.

The majority of LWR operational wastes by volume is comprised of low-level activity items such as filters, filter backwash, filtered phase-separator decant liquid, evaporator bottoms, demineralizer wastes, laundry wastes and general trash. The estimated average activity for operational waste is 1.3 Ci/m^3. The isotopic concentrations are listed in Volume 1.

The method of deriving the isotopic concentrations together with various assumptions are discussed in Smith 1979. A key assumption is that the percentages of the four major isotopes, Co-60, Cs-137, Mn-54 and Cs-134 which are typically found, and BWR and PWR evaporator bottoms and spent resin wastes may be applied to the total activity.

The concentrations of additional radioisotopes were included on the following bases:

1. Selecting representative values from published data, when spread in data is very large.
2. Selecting maximum values, when only a few values are available.
3. Calculating the concentration from theoretical considerations or from combination of actual concentration data and theoretical extrapolations.

Radionuclide inventory for these wastes is summarized in Volume 1.

LWR decommissioning wastes are derived from activation of structural components and decontamination. Isotopes contained in activated components are summarized in Volume 1. They were derived in AIF 1976 and NRC 1977 on the basis of material composition and neutron fluxes in the reactor. The accuracy of predictions is expected to be good for the activation products of the major structural materials. The average specific activity was estimated at 3.8 Ci/m^3 with major contributors being Co-60, Ni-63 and Fe-55. The remaining isotopes are listed in Volume 1.

The decontamination wastes in the LWR decommissioning models are assumed to have a similar composition to LWR operational wastes, listed in Volume 1. However, an average specific activity is 32 Ci/m^3 which is considerably higher than 1.3 Ci/m^3 for operational wastes.

4.3 NON-FUEL CYCLE WASTES

In 1978, there were more than 16,000 licensees in the United States licensed for the use of radioactive materials by either individual states or the Nuclear Regulatory Commission (Andersen, et al, 1978). These licensees are the producers of non-fuel cycle wastes. It is estimated that a significant portion of the non-fuel cycle wastes is produced by a relatively small number of large medical and educational institutions and certain industrial licensees.

4.3.1 Institutional Waste

A study was performed to characterize the wastes produced by a significant portion of institutions and shipped for commercial burial (Andersen, et al, 1976). The study was accomplished by the use of a survey of selected institutions and covered data for 1975. In 1975, it was estimated that 39 percent (by volume) of all low-level waste was from non-fuel cycle sources. The major results and conclusions are discussed in the following paragraphs.

The waste containers used for shipment were:

- 210-liter (55-gallon) steel drums (62 percent).
- 115-liter (30-gallon) steel drums (30 percent).
- Other containers (8 percent).

The other containers included fiberboard drums, cardboard boxes, wooden crates, paint cans, etc. The use of 115-liter versus 210-liter cans appeared to be strictly for ease of handling.

The physical forms (by volume) of the shipped waste were:

- Dry solid waste (42 percent).
- Scintillation vials (28 percent).
- Solidified and absorbed liquid waste (21 percent).
- Biological waste (9 percent).

Assuming at least 50 percent of the solidified and absorbed liquids consisted of expended scintillation cocktail, then nearly 40 percent of all waste by volume consisted of packaged scintillation cocktail or scintillation vials.

Table 4-4 lists the estimated radionuclides shipped in 1975 by category. The miscellaneous radionuclides included:

Ca-45
Co-57
Cs-137
Fe-59
In-111
Hg-203
Cd-109
Xe-133
Se-75
Sr-85
Co-60
Rb-86
Mg-56
Ra-226
Na-22
Yb-169
Mn-54
I-123
Ir-192
Ce-141
Am-241

Table 4-5 lists the estimated activity concentrations using the assumptions included with the table. Figure 4-1 is Andersen's projected volume of institutional waste for the years past 1975. Andersen noted that the volume trends given are likely to be conservative since the study based trends on a constant population. The average specific activitiesare summarized in Volume 1, with the tritium activity adjusted to account for tritium accelerator targets. The isotopes for which concentrations are identified as "very small" were reported by the survey respondents, but the concentrations could not be projected because of insufficient sampling.

4.3.2 Other Non-Fuel Cycle Wastes

No breakdown on the other non-fuel cycle wastes was available. Therefore, institutional waste is currently assumed to be representative of all non-fuel cycle wastes. The inventories are summarized in Volume 1.

4.4 ESTIMATED RADIONUCLIDE CONCENTRATIONS IN LOW-LEVEL WASTE

Table 4-6 is a listing of estimated radionuclide concentrations in low-level waste. The data is taken from an NRC document (Smith, 1979). It was assumed that no decay during transit to a site occurs. Nuclides with half-lives less than 50 days or for which only limited evidence of their existence was found were excluded. Table 4-7 lists these radionuclides.

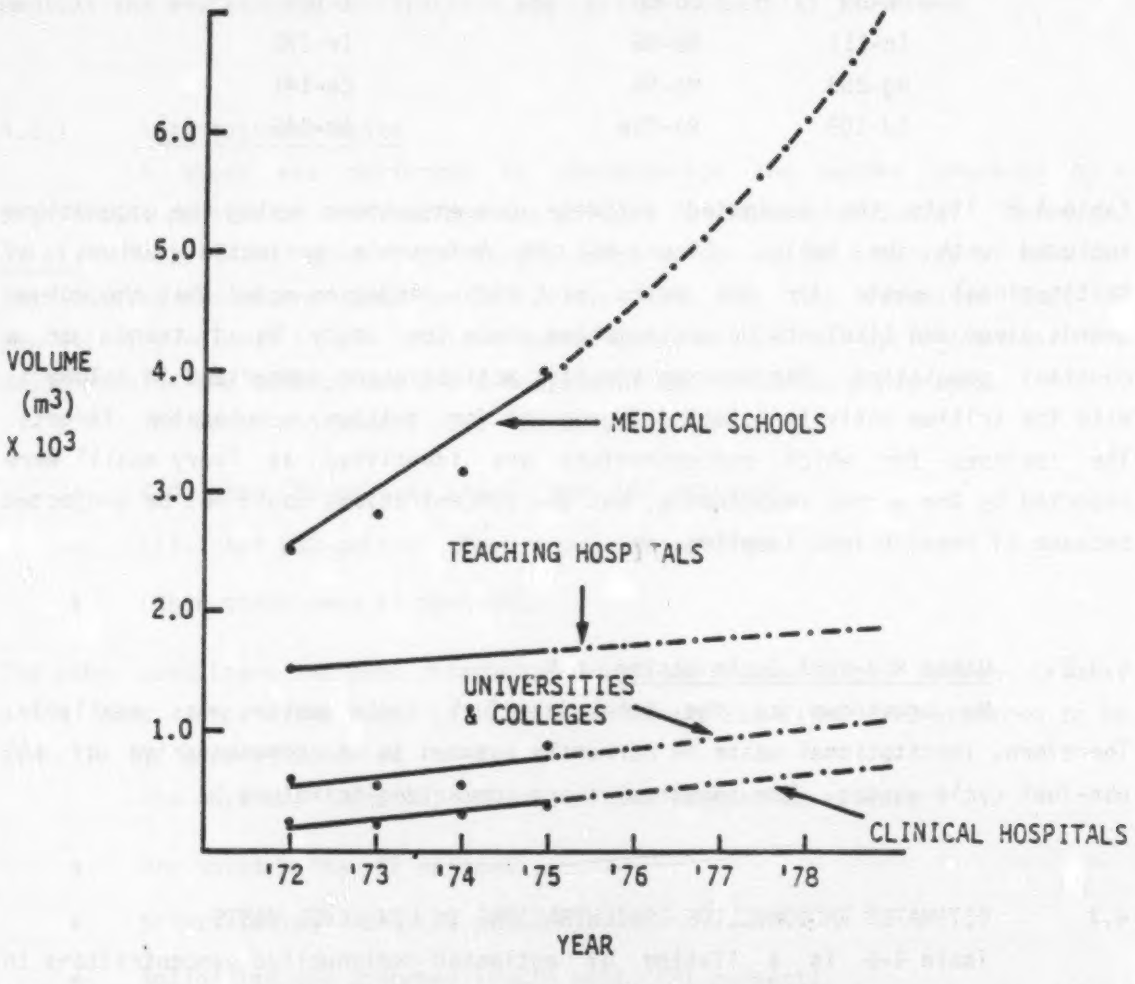


Figure 4-1. Projected Waste Volume Increases in Institutional Survey Population. (Andersen, et al, 1976).

Table 4-4. Estimated Institutional Radionuclides Shipped for Commercial Shallow Land Burial in 1975 (Activities in mCi) (Andersen *et al*, 1976).

NUCLIDE	CLINICAL HOSPITAL	TEACHING HOSPITAL	MEDICAL SCHOOL	UNIVERSITY/ COLLEGE	TOTAL
H-3*	1,313	13,788	46,659	23,516	85,276
C-14	214	1,523	19,585	4,788	26,114
P-32	41	2,085	11,256	2,024	15,407
S-35	0	360	4,426	1,149	5,935
Cr-51	113	438	3,495	612	4,658
Ga-67	21	264	33	0	318
Tc-99m	9,021	76,614	4,813	0	90,448
I-125	174	4,998	23,564	2,816	10,342
I-131	105	15,324	1,310	561	17,300
Misc.	403	2,890	25,182	8,771	37,246

*Tritium accelerator tragets excluded.

Table 4-5. Estimated Institutional Activity Concentrations of Wastes Shipped for Burial (Andersen et al, 1976) (mCi/m^3)

NUCLIDE	CLINICAL HOSPITALS	TEACHING HOSPITALS	MEDICAL SCHOOLS	UNIVERSITIES/ COLLEGES	TOTAL POPU- LATION
H-3	4.48	8.72	10.97	31.99	12.43
C-14	0.74	0.96	4.61	6.51	3.81
P-32	0.14	1.32	2.65	2.75	2.25
S-35	0	0.23	1.04	1.56	0.86
Cr-51	0.39	0.28	0.82	0.83	0.68
Ga-67	0.13	0.32	0.01	0	0.07
Tc-99m	57.09	91.42	1.78	0	21.26
I-125	0.59	3.16	5.54	3.83	1.51
I-131	0.66	18.29	0.49	1.14	4.07

Assumptions for Concentration Estimates:

(1) No radiopharmaceutical nuclides in scintillation fluids.

(2) 50% of solidified and adsorbed liquids are scintillation fluids.

(3) Remaining nuclides are uniformly distributed through waste.

Table 4-6. Estimated Radionuclide Concentrations in Low-Level Waste.

RADIONUCLIDE	CONCENTRATION (Ci/m^3)	SOURCE*
H-3	** 1.2 - 01	1
C-14	3.8 - 03	1
S-35	8.6 - 04	1
Mn-54	7.5 - 01	2
Fe-55	4.3 - 01	2
Co-58	4.3 - 01	2
Co-60	1.3 + 00	3
Ni-59	1.3 - 02	3
Ni-63	2.4 + 00	3
Zn-65	2.0 - 02	2
Sr-90	4.8 - 03	2
Nb-94	1.4 - 04	3
Zr-95	2.0 - 02	2
Tc-99	3.1 - 05	2
Ru-105	2.0 - 02	2
Sb-124	5.0 - 03	2
Sb-125	5.0 - 03	2
I-125	1.5 - 03	1
I-129	6.4 - 06	2
Cs-134	4.8 - 01	2
Cs-135	3.2 - 05	2
Cs-137	8.6 - 01	2
Ce-144	2.0 - 02	2
Eu-152	4.8 - 05	2
Eu-154	4.8 - 04	2
Eu-155	4.8 - 04	2
Ra-266	1.15 - 04	4
Th-230	7.3 - 05	4

continued...

Table 4-6. (Continued) Estimated Radionuclide Concentrations in Low-Level Waste.

RADIONUCLIDE	CONCENTRATION (Ci/m^3)	SOURCE*
Th-232	8.4 - 06	4
U-235	3.2 - 05	4
U-238	7.2 - 04	4
Np-237	4.6 - 08	2
Pu-238	3.1 - 04	2
Pu-239	4.3 - 05	2
Pu-240	6.7 - 05	2
Pu-241	1.65- 02	2
Pu-242	2.4 - 07	2
Am-241	3.0 - 05	2
Am-242m	1.6 - 06	2
Am-243	2.1 - 06	2
Cm-242	2.5 - 03	2
Cm-243	6.0 - 07	2
Cm-244	1.9 - 04	2

*Source of Waste:

1 — Non-Fuel Cycle

2 — LWR Operations

3 — LWR Decommissioning

4 — Non-Fuel Cycle (taken from actual site data files)

** 1.2-01 = $1.2x10^{-1}$

Table 4-7. Other Potential Radionuclides in Low-Level Waste Not in Table 3.6

RADIONUCLIDE	CONCENTRATION (Ci/m^3)
P-32	* 2.3 - 03
Cr-51	5.8 - 04
Fe-59	-
Ga-67	7.0 - 05
Sr-89	-
Nb-95	-
Ag-110m	-
I-131	4.0 - 03
Cs-136	-
Cs-141	-

* 2.3-03 = 2.3×10^{-3}

4.4.1 Composite Inventory

Composite wastes from different sources are placed in a single trench which might be 20 to 30 m wide, 10 to 15 m deep and several hundred meters long. After a period of time the packaging disintegrates and for the purpose of modelling, the wastes in the trench can be represented by a single characteristic composition. This representative inventory is summarized in Volume 1. Only the parent isotopes of the decay chains are identified.

4.4.2 Physical Properties of Wastes

The pathways that the radionuclides can enter when released accidently from their containers are dependent on the physical properties of the waste materials, i.e.:

1. Wastes are solid, e.g., imbedded in concrete, asphalt or similar binder.
2. Wastes are liquids, e.g., contained in vials.
3. Wastes packages contain gases as for example from disintegration of packaged materials.
4. Wastes are soluble in water
5. Wastes are burnable, e.g., paper, rubber gloves, etc.
6. Wastes are dispersable by wind, e.g., powder, dust, light papers, etc.

4.4.3 Packaging of Wastes

The packaging provides containment and/or shielding of wastes during transportation and pre-burial operations. Sometimes after the burial, the packages disintegrate and do not provide either containment or shielding.

A large variety of packaging methods and containers are in use, ranging from heavily shielded casks to loosely bound bundles. These were described in detail in D. Lester (1979). To reduce this variability to manageable proportions, the following generic categorizations were adapted in the descriptions of release scenarios in Volume 3, Appendix C.

1. A heavy cask with shielding material encloses a removable liner containing wastes. This type of packaging is used for the shipments of highly activated LWR components, e.g., those with specific activities of several thousand curies per cubic meter of wastes. Typically, the

cask is large and is carried singly on the transport vehicle. Only the liner with the wastes is buried and the cask is released for reuse.

2. Wastes with low specific activities are packed in drums, wooden boxes, cartons, or in a variety of smaller containers such as paint cans, etc. Some are bound into bundles or packaged in plastic bags.

3. For transportation, the individual packages may be placed in overpacks which are then transported on trucks. The overpacks may be shielded.

4. Waste packages may be transported loosly in a covered van. At the burial site, the individual packages are removed from the van or overpack for placement in the trench.

The potential accidents may involve a large number of packages such as burning of the total content of the transport vehicle or flooding of an unburied part of the trench; or may involve only individual packages such as rupture of a drum or a box during on-site handling.

4.5 RELEASE FRACTIONS (SOURCE TERM DATA BASE)

The inventories of radionuclides identified are seldom released in their entirety. However, some guidance can be provided for the analysis of generic cases based on the evaluations of similar events in the study of the Waste Isolation Pilot Plant (DOE, 1979) and the management of buried transuranic waste at the INEL (DOE, 1979). Estimates of release fractions (RFs) which might be considered as representative examples are summarized in Table 4-8 for all relevant initiating events. The assumptions made in the development of each specific value are described in the text. The value of RF is defined as the ratio of quantity of radionuclides released to the pathway to the total content of the radionuclide in the inventory which is being analyzed. For example, when considering fire in the overpack, during on-site arrival phase, the quantity involved is the content of the overpack. When considering the fire in unburied trench, the quantity of waste involved will be the content of unburied trench.

With the exception of activated components, they are mostly in the form of particulate material adhering to cloth, glass, metal, plastic, etc. They may be contained in liquids, although this waste form is generally unacceptable unless present in very small quantities. More likely, they might be in a sludge-like form. One important class of wastes is those fixed in cement or in asphalt.

Table 4-8. Summary of Representative Release Fractions.

Chronic Release of Direct Radiation:	1-3 mr/hr
Chronic Contamination:	
(a) Site	10^{-3} (of processed quantity)
(b) Airborne	10^{-5} (of processed quantity)
Container Rupture:	
(a) Site	10^{-1} (of container contents)
(b) Airborne	10^{-3} (of container contents)
Waste Fire:	
(a) Site	2×10^{-5} (of burned contents)
(b) Airborne	2×10^{-2} (of burned content)
Waste Explosion/Airborne:	10^{-3} (of exploded contents)
Rain/Flood:	
(a) Site	10^{-4} (of flooded contents)
(b) Airborne	3×10^{-7} (of flooded contents)
Wind:	2×10^{-1} (of affected contents)

Because of the large variations in the physical forms and properties of the wastes, the release fractions resulting from the accidental or chronic release must be determined on the basis of the specifics of the release. For example, a much smaller fraction of the radionuclides will be released from a rupture of the drum containing wastes fixed in asphalt or cement than from a similar rupture of waste package containing powder-like solids.

4.5.1 Chronic Release of Direct Radiation

It is expected that a number of measures will be taken to control these occupational hazards to within normally accepted levels. The radiation levels to which workers are exposed will be monitored by health-physics personnel; radiation doses will be held to levels as low as practicable by the requirement to follow specified procedures. The daily accumulated doses will be monitored. As an example of what values are to be expected, DOE estimates the radiation level at the surface of a drum to be about 3 mr/hr and at the surface of a box 1 mr/hr.

4.5.2 Chronic Contamination

To minimize the possibility of contamination, the site personnel will work in dust-tight enclosures, will wear protective clothing, and will be provided with respiratory protection as needed. Workers will be surveyed frequently whenever the possibility of external contamination exists. Continuous air sampling and radiation monitoring instruments in the work areas will promptly detect and annunciate abnormal or accident conditions. Special procedures will be established for evacuating personnel, controlling spread of contamination and correcting accident conditions.

In DOE, 1979, it was assumed that an average 1 percent of the containers will be breached during handling. It was further assumed that 10 percent of the radionuclides will be released to the environment with 1 percent of those released becoming resuspended. Based on these values, the release fraction to the soil is 10^{-3} and release fraction to the air is 10^{-5} of the quantity handled at the site.

4.5.3 Container Rupture and Waste Spill

Reference DOE, 1979 estimates the effects of possible releases from container rupture. According to the assumption made in the reference, 0.1 of the activity will be released to environment with 0.01 of the released radioactivity becoming resuspended. This results in an overall release fraction of 10^{-1} per container released to the soil and 10^{-3} per container becoming airborne which average release rate in pCi/sec and maximum cumulative concentrations in soil (nCi/m^2) for each isotope can be calculated from these values for quantities of wastes which are being analyzed.

4.5.4 Waste Fires

DOE's predecessor, ERDA, has performed studies of prolonged fires circa 1975 (DOE, 1979). In these studies release fractions to the atmosphere of 0.1 to 0.5 were assumed. Because typically about 20 percent of the waste is combustible, a release fraction to the atmosphere of 0.02 to 0.1 might be appropriate for the analysis of generic cases. Since flooding with water assumes a release fraction to soil of 10^{-4} the release fraction to soil for fires extinguished with water is $2x10^{-5}$.

4.5.5 Waste Explosions

Explosions have been studied by Mishima and others (DOE, 1979). Reference 7 assumed on this basis that 0.1 percent of the waste remains airborne and might be carried offsite. Consequently, for the analysis of generic cases, a release fraction of 10^{-3} may be used.

4.5.6 Rain/Flood

The flooding of buried wastes could cause a radiological hazard to the public by means of two pathways: (1) ingestion of contaminated drinking water, and (2) inhalation of airborne nuclides released via resuspension.

The ingestion pathway would include (1) infiltration of water into the waste buried in trenches, (2) leaching of radionuclides from buried waste, and contaminated solid, and (3) percolation of the leached radionuclides into the aquifer and subsequently into drinking wells.

In estimating the release fraction for this mechanism, it is assumed that the flood waters would percolate in a saturated flow (i.e., at full flow capacity in porous media) toward the aquifer. Radionuclides migrating with percolating water would be in dissolved or colloidal suspension form. Some of the dissolved species may be chelated or otherwise complexed. Radionuclides that are sorbed or filtered would not have a flow pathway to reach the aquifer and the migration will be significantly retarded. In DOE it was assumed that less than 10 percent of the radionuclide inventory would be in appropriate dissolved, chelated or colloidal suspension form. At low concentrations, ion exchange and absorption mechanisms would be extremely effective. It may therefore be assumed that less than 0.1 percent of the migrating waste would reach an aquifer located several hundred meters away. A release fraction of 10^{-4} is therefore suggested for generic cases.

The resuspension pathway would include (1) scouring of waste via movement of soil from the waste trenches to a new area (assume 1 percent of the waste can be scoured), (2) subsiding of water level in the contaminated area leaving transported waste in the top one inch of the sediment (assume 10 percent of transported waste), (3) drying of the mud and lofting particles less than 10 microns in diameter (assume fraction of particles smaller than 10 microns is 3×10^{-3}). This results in the release fraction for resuspension pathways of 3×10^{-7}.

4.5.7 Winds

These events are applicable to the sites which might be located in the high wind localities. An extensive study of tornadoes in the Western United States was performed by Fujita, 1971. Based on this study, it is estimated that the average tornado will result in a damage zone of 0.01 square mile and would have a velocity of 100 mph. The clay protective cover over the waste will resist tornado winds during the short term and no radioactive releases would be expected. If the high winds should occur during the time when wastes are uncovered 20 percent - a number similar to that assumed as being combustible - might be considered wind dispersable.

5. RADIONUCLIDE RELEASE SCENARIOS

5.1 RADIONUCLIDE PATHWAYS

5.1.1 Introduction

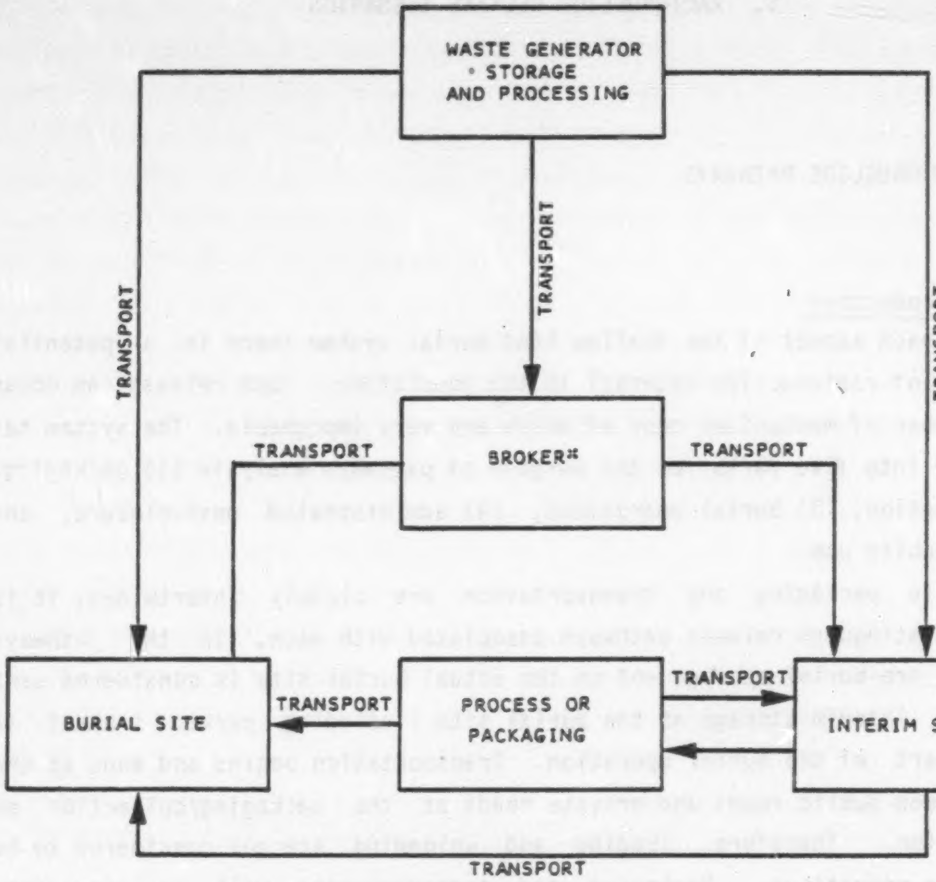
In each aspect of the shallow land burial system there is a potential for release of radionuclide material to the population. Such release can occur through a number of mechanisms many of which are very improbable. The system has been divided into five parts for the purpose of pathways analysis (1) packaging, (2) transportation, (3) burial operations, (4) administrated post-closure, and (5) limited public use.

While packaging and transportation are closely intertwined, it is possible to distinguish release pathways associated with each. In the pathways analysis, any pre-burial storage not on the actual burial site is considered part of packaging. Interim storage at the burial site (including parked trucks) is considered part of the burial operation. Transportation begins and ends at the boundary between public roads and private roads at the packaging/collection or burial location. Therefore, loading and unloading are not considered to be transportation operations. Packaging and transportation will be considered non-site-specific as it is possible to do a reasonable generic analysis based on a national system. Therefore, only one set of pathways will be described for transportation and for packaging.

The pathways associated with burial operations and subsequent site activities can be highly site-specific. Therefore, in the following sections separate pathways are presented for each existing site and for reference sites.

5.1.1.1 Packaging and Transportation

Figure 5-1 is a logic diagram of the interaction of packaging, interim storage, and transportation of low-level waste. Although transportation and packaging can be interspersed, the release pathway scenarios for each can be


WASTE GENERATOR
STORAGE
AND PROCESSING
TRANSPORT
TRANSPORT
TRANSPORT
TRANSPORT
BROKER*
TRANSPORT
TRANSPORT
BURIAL SITE
TRANSPORT
PROCESS OR
PACKAGING
INTERIM STORAGE
TRANSPORT

* BROKER COLLECTS FROM MANY GENERATORS

Figure 5-1. Low-Level Waste Burial Operations.

separated for the purpose of modeling. The diagram is presented to illustrate that the frequency associated with transportation pathways can be a variable dependent on waste gathering/packaging/transport logistics.

In many cases, brokers collect waste from a number of sources (two shown in Figure 5-1). Broker activities can include additional processing, immediate shipment to the burial ground, or storage with subsequent shipment. Because of the nature of collection from several sources, there is some interim storage of at least a short duration.

5.1.1.2 Burial Operations

Pathways from burial operations can be highly site-dependent from the standpoints of (1) nature of the operation and (2) site characteristics. Figure 5-2 presents burial operation with variations normally encountered at existing sites and anticipated to occur in the future. Depending on the path of operation sequence through this diagram, there will be varying release pathway possibilities. The pathways analysis for the individual existing sites reflects this uniqueness. Reference site pathways analysis should attempt to generalize on all possible sequences in Figure 5-2.

Burial generation begins with arrival of waste on the site and includes all receiving and unloading operations in addition to burial activities. During receiving, the site personnel may have to deal with truck contamination, package leakage, and other related problems. Decontamination procedures and subsequent unloading difficulties can potentially include a number of radionuclide release pathways, especially if sandblasting, steam cleaning, or overpacking activities are involved. Package problems encountered during unloading (such as rupture or leakage) can sometimes result in releases which depend heavily on the types of waste handled (intensity, type, and liquid content). One of the largest operational variables involves unloading procedures. These can vary from dumping to lowering to driving waste into trenches. The trench structure (depth, type of soil, etc.) can also have a significant effect on potential releases during unloading. Subsequent operational practices, such as frequency of waste covering, affect emplacement release. However, it is during the post-emplacement, post-burial period, while the site is still in operation that site geologic/meteorologic characteristics dominate radionuclide release path scenarios.

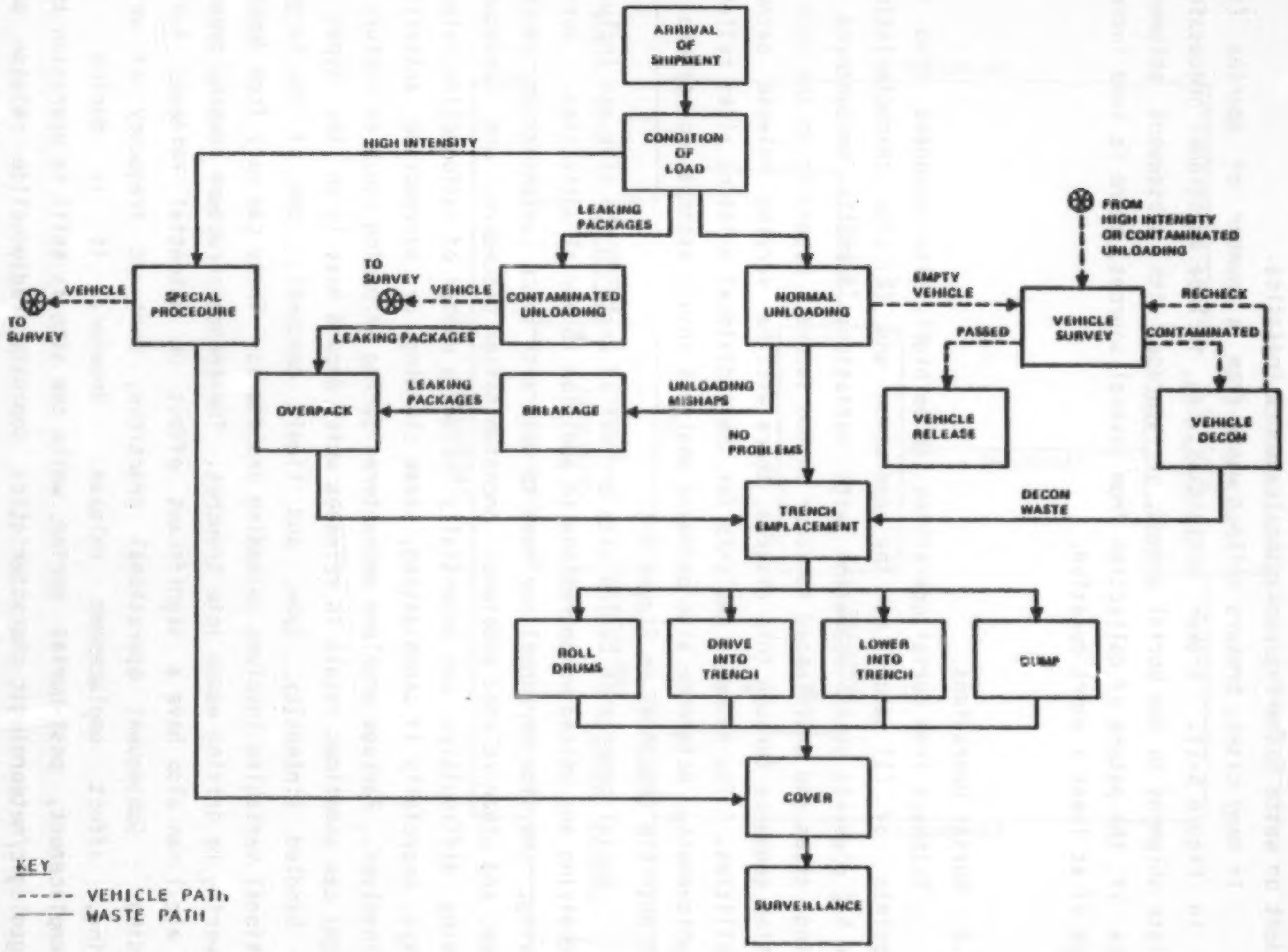

ARRIVAL OF SHIPMENT
CONDITION OF LOAD
HIGH INTENSITY
LEAKING PACKAGES
SPECIAL PROCEDURE
VEHICLE
TO SURVEY
CONTAMINATED UNLOADING
VEHICLE
TO SURVEY
LEAKING PACKAGES
NORMAL UNLOADING
EMPTY VEHICLE
FROM HIGH INTENSITY OR CONTAMINATED UNLOADING
VEHICLE SURVEY
RECHECK
PASSED
CONTAMINATED
VEHICLE RELEASE
VEHICLE DECON
OVERPACK
LEAKING PACKAGES
BREAKAGE
UNLOADING MISHAPS
NO PROBLEMS
TRENCH EMPLACEMENT
DECON WASTE
ROLL DRUMS
DRIVE INTO TRENCH
LOWER INTO TRENCH
DUMP
COVER
SURVEILLANCE
KEY
----- VEHICLE PATH
—— WASTE PATH

Figure 5-2. Low-Level Waste Burial Site Operations.

5.1.1.3 Post-Closure - Administrative Period

During this period, the site is still under administrative control. Management of radionuclide releases can be exercised through groundwater management, surface runoff management, and leachate processing. In addition, access to the site and use of the land is under tight administrative control. Maxey Flats is an example of a site currently operating under such conditions. Release pathways during the post-closure period depend mainly on the as-buried condition of the waste, the geologic/hydrologic environment, and the nature of post-closure administration.

5.1.1.4 Limited Use Period

During this period, there is little or no site management activity. The land is released for public use which would be tailored for minimal disturbance of the burial areas (i.e., no significant excavation or drilling). An example of such use would be a park or golf course. Radionuclide release pathways will depend strongly on the as-buried condition of the waste and site geology/hydrology. Because of lack of administrative control, a fairly extensive list of event-type and chronic pathways is possible during this period. Examples of such pathways are human intrusion, animal intrusion, crop or plant absorption, and natural disruptions (flood, seismic activity, etc.).

5.1.2 Packaging and Handling

Packaging and handling operations include gathering, processing, and interim storage. The gathering operation may be quite simple if the waste is generated and processed at a single source or complex as in the case of a large university with a number of laboratories, a reactor, and a hospital. There are a variety of processing operations ranging from simply packaging of the waste in a form suitable for shipment to involved incineration or solidification processes. Interim storage may occur at the waste-generating site itself or it may occur in several stages. Interim storage will occur in several stages when waste broker services are used for final disposal, and may result in a rather complex set of transfer and storage operations.

Section 5.1.2.1 discusses low level waste (LLW) packaging forms and the types of facilities from which they originate. Section 5.1.2.2 describes various processes which may be used for volume reduction, immobilization, and increased safety for LLW. Finally, Section 5.2.2.3 lists and describes the various pathways by which radionuclides within the low-level waste could reach the environment in the course of the packaging and handling operations.

5.1.2.1 Packaging

The low-level waste packaging criteria are determined by the Department of Transportation (DOT) regulations as well as by the site regulations and state rules. DOT classifies waste as Low Specific Activity (LSA) Type A, Type B, or large quantities by a set of definitions in 49 CFR 170-199. LSA wastes do not require any more than strong, tight industrial packaging when shipped by a sole-use vehicle, but DOT-approved packaging must be used when they are shipped on a common carrier. Type A wastes are defined as those having a content of not more than 20 curies, but more hazardous nuclides have lower limits (e.g., 3 Ci for Co-60 and Cs-137 and significantly less for heavy metals with long half lives). Type B quantities are typically a factor of ten above Type A, and large quantities are those that exceed Type B quantities.

The packaging for the shipment of Type A quantities must meet the DOT specification 7A for Type A general packaging, 49 CFR 178.350. Prior to 1976, a large variety of DOT-approved Type A containers were listed in 49 CFR 173.395 including metal and fiber drums and fiber and wooden boxes in a range of sizes. Specifications for each are given in 49 CFR 178. The specifications list size, configuration, types and thickness of materials of construction, type of closures, pre-use testing, limitation on contents, and external markings. Other Type A packaging available includes steel and concrete bins and shielded containers. Beginning in 1976, paragraph 173.395 was modified to delete approval for specific containers and now gives approval only for containers meeting the general 7A specification. However, this paragraph had a large affect on the state-of-the-art of containers, particularly in the use of DOT Specification 17H steel drums (Holcomb, 1978).

Type B quantities and large quantity shipments must use a DOT specification 6M container or specially-approved Type B containers. Approval of these containers and a Certification of Compliance may be received from the NRC by compliance with the regulations in 10 CRF 71.

The most common container used for packaging low-level wastes for disposal by shallow land burial is the steel drum. The 210-liter drum is most common but 125-liter and smaller drums are also used. These are usually painted on all surfaces for corrosion resistance. For some applications, plastic bags or rigid liners are used for additional containment. Steel drums are relatively inexpensive, easy to load and handle, and have been acceptable for disposal at all burial grounds. DOT-approved steel drums serve as Type A packaging for the shipment of Type A quantities and LSA waste. The wastes can be loaded into the drums at the waste collection area, the drums can be shipped by common carrier to the disposal site, and the drummed waste can be placed directly into the burial trench. Where radiation levels must be reduced to meet DOT external dose rate requirements a concrete liner or other suitable shielding material may be placed in the drum within the weight limitation of the drum. Wet wastes which require solidification prior to disposal are often mixed wth a solidifying agent, such as cement or urea formaldehyde resin, and cast directly into a drum. Often the drum is used as a receptacle into which loose trash is compacted prior to disposal. Dewatered ion exchange resins and sludges are loaded directly into drums at some sites but these have not been acceptable for disposal at all burial grounds because of their moisture content. For some highly mobile wastes, such as tritium, it is common practice to utilize a sealed inner metal or plastic liner, or a polymeric sealed concrete matrix within the outer metal drum as an additional barrier for the containment of the waste.

Steel drums are also utilized as packaging for Type B or larger quantities and high-radiation-level Type A quantities of radioactive wastes where the drum does not qualify as a shipping package. In this case, the drums are shipped in an overpack which serves as the approved shipping container. For example, unshielded Type B overpacks are available which can hold 42 drums of 210-liters each for transport by truck, rail, or cargo vessel. Shielded Type B overpacks are typically smaller in size and capacity so that the total weight does not exceed the limits for truck shipments. When delivered to the burial ground, the drums are withdrawn from the Type B container and placed into the burial trench; the shipping container is returned for reuse.

Larger metal containers have found increased use where large volumes of waste products must be disposed of on a routine basis. It has been found more economical to use containers with ten or more times greater capacity than the 210-liter drum. Waste packages of this size must be shipped in an overpack so the containers are designed as disposable liners for specific DOT-approved shipping containers. These large containers are commonly used for shipping used ion exchange resin from commercial power reactors. Low-activity resins may be shipped in 4.5 to 5.1 m^3 liners in a overpack with shielding equivalent to 50 mm of lead. Resins with a higher specific activity may qualify as Type B or large quantities and may be shipped in 2.0 m^3 liners which require an overpack with shielding equivalent to 100 mm of lead. These large metal containers are made in a cylindrical configuration of carbon steel with welded seams. The containers have a relatively thin (nominally 5.4 mm) wall and are equipped with lifting lugs and fittings for filling, venting, and removing water.

5.1.2.2 Treatment Processes

The treatment of high-level waste prior to packaging is performed to reduce the volume required for storage and disposal, to increase the margin of safety in handling and storage operations, and to reduce the mobility of the wastes subsequent to burial operations.

Solid Wastes

Solid wastes consist of many materials discarded from a facility and contain both combustible and noncombustible materials (Cooley and Clark, 1976).

Combustible solids consist of a large variety of items, such as paper, rags, plastic sheeting, protective clothing, gloves, rubber shoes, wood, and filter cartridges, as well as some partially combustible items, such as HEPA filters encased in wooden frames. The actual constituents in combustible waste vary, depending on the location of operations generating the wastes.

The noncombustible fraction consists typically of metal and glassware, construction and insulation materials (concrete, mortar, etc.), metal-encased HEPA filters, and small discarded equipment, tools, metal filters, and other mechanical devices.

General trash almost always consists of both combustible and noncombustible materials, and pretreatment operations are often required prior to primary treatments. Pretreatment of waste, that is, the physical or chemical processes necessary to prepare waste for primary treatment and/or storage, includes such operations as assay, sorting, shredding, and classification. In general, the technologies for pretreatment operations are readily available and have been used at DOE facilities and commercial sites.

Frequently, it is desirable to segregate solid wastes into combustible and noncombustible fractions. After suitable pretreatment, combustible wastes can be burned, decontaminated, compacted, or packaged. Similarly, noncombustible materials can be decontaminated, compacted, melt-cast, dissolved, and/or packaged.

Shredding is used on potentially-combustible waste materials to produce small pieces for subsequent processing or storage. The principal types of shredding equipment are knife cutters, hammermills, or combinations of these devices.

Commercially-available knife cutters used for size reduction are grouped into three broad categories (1) fly knives mounted tangentially on a rotor to work against stationary bed knives, (2) finger knives mounted axially on a rotor to work against stationary anvils, and (3) finger knives mounted axially on two counterrotating rotors. Fly-knife cutters have the disadvantage of being susceptible to damage from tramp metal in the feed. The knives must be sharpened or replaced periodically.

Hammermills consist of pivoted or rigidly-mounted hammers on a vertical or horizontal shaft or rotor. The hammers may be rectangular or chisel-shaped. Crushing or shredding takes place by impact between the hammers and a breaker plate. These shredders are more effective on brittle and noncombustible wastes. They are less useful for shredding plastics because of the tendency of these materials to bind the hammers.

Compaction is the simplest process for reducing the volume of trash for disposal. Compactors are widely used in the nuclear industry for reducing the volumes of general trash and combustible wastes. The technology is well established for commercial application. In compaction, the waste is compressed inside a container (such as a 210-liter drum) which is then closed. Some wastes are also amenable to a baling operation in which the wastes are compressed and then banded so that they cannot expand. The bale can be subsequently packaged for further disposition. For example, they are often packed in plywood boxes.

There are a variety of combustion treatments used and under development for radioactive wastes. These include incineration, pyrolysis, acid digestion, and molten-salt combustion. Incineration involves the burning of combustible materials in air or in an oxygen-rich atmosphere. Pyrolysis is the heating of the wastes in an oxygen-deficient atmosphere and results in a gasification of part of the waste material. Acid digestion consists of oxidation by nitric acid in a concentrated sulfuric acid medium. Molten-salt combustion uses air oxidation in a molten-salt environment.

The application of combustion or incineration to the treatment of combustible solids requires the coupling of several processes or unit operations into a total waste-treatment system (Figure 5-3) that includes feeding, incineration, off-gas treatment, and ash/residue packaging or immobilization. Some waste materials (e.g., chlorinated rubbers or plastics) impose more stringent requirements on the design because of the generation of soot and because of corrosion by hydrochloric acid vapor produced during combustion. Special design features are required to contain the radioactivity and to provide adequate personnel protection. The incineration of combustibles has been widely used as a radioactive waste treatment.

Liquid Waste Solidification Processes

Liquid wastes consist of aqueous solutions and slurries, evaporator concentrates, spent demineralizer resins, filters and filter sludges, and organic oils and solvents. Technologies for solidifying these wastes include evaporation, reverse osmosis, combustion, ion exchange, chemical solidification, cement, and bitumen. The choice of the process depends on the type of waste, facility, volume, and costs. Although calcination and vitrification have been proposed for some wastes, especially TRU wastes generated at DOE facilities, the high cost and energy-intensive nature of these processes make them unattractive for most applications.

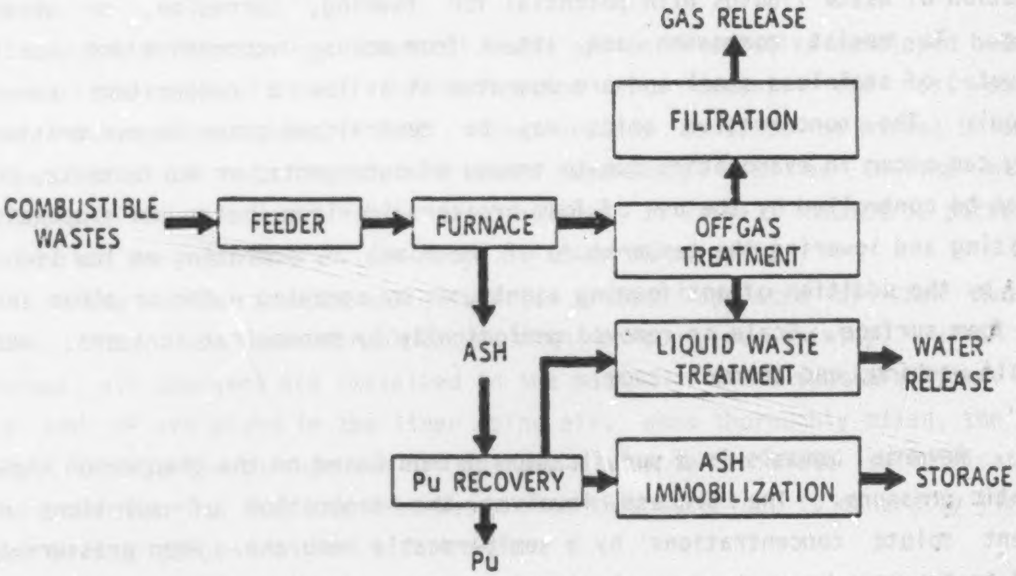

GAS RELEASE
FILTRATION
COMBUSTIBLE WASTES
FEEDER
FURNACE
OFFGAS TREATMENT
ASH
LIQUID WASTE TREATMENT
WATER RELEASE
Pu RECOVERY
ASH IMMOBILIZATION
STORAGE
Pu

Figure 5-3. Schematic of Typical Combustion System.

Evaporation is a process whereby a solution or slurry is concentrated by vaporizing or boiling away the solvent, normally water or mineral acid. Evaporators coupled to efficient deentrainment devices provide capability for a high degree of separation for most radioactive materials. The inherently high operating cost of evaporation limits the applications to those liquids that have a high concentration of dissolved solids and require high decontamination factors (Cooley and Clark, 1976).

An evaporator consists basically of a device to transfer heat to the solution and a device to separate the vapor and liquid phases. The principal element involved in evaporator design are heat transfer, vapor-liquid separation, and energy utilization. Careful design of equipment is mandatory for the evaporation of waste liquids with potential for foaming, corrosion, or severe scaling. To resist corrosion and attack from acids, evaporators are usually constructed of stainless steel and are operated at as low a temperature as is practical. The noncorrosive acids may be neutralized prior to evaporation. Foaming can occur in evaporators due to traces of detergents, or surfactants, but this can be controlled by the use of foam breakers (devices inside the evaporator for raising and lowering the temperature of the foam), by operating at low liquid levels, by the addition of antifoaming agents, or by spraying water or steam jets on the foam surface. Scale is removed periodically by mechanical scrapers, acid or alkali washing, and thermal shock.

Reverse osmosis is a purification method based on the phenomenon known as osmotic pressure. The process involves the separation of solutions of different solute concentrations by a semipermeable membrane. When pressure is applied to the more concentrated solution in excess of its osmotic pressure, solvent will flow across the membrane to the less concentrated side.

Waste organic liquids can be burned by spraying into specially-adapted oil burners or conventional incinerators used for combustible wastes. The special nature of spent solvents containing radioactivity and phosphorus imposes demanding requirements for off-gas treatment. Although the technology is generally available for solvent incineration, it has not been fully reduced to operating practice. Current work at the Savannah River Plant and the Barnwell Nuclear Fuel Plant is expected to demonstrate such processes. Alternatively, evaporation of small volumes of volatile organic liquids is also a viable decontamination option. More commonly, because of their small volume, liquids or semi-liquids have been absorbed on vermiculite or similar absorbents for disposal without further treatment (Cooley and Clark, 1976).

Ion-exchange methods have been widely used for removing dissolved radioactivity from low-level liquid wastes. The process involves the exchange of ions between the liquid and a solid matrix containing ionizable polar groups. Both cation- and anion-exchange resins and zeolites are used. When the exchangers have become fully loaded, they are removed from service and treated as radioactive waste; alternatively, they may be regenerated by strong acids and strong bases thus yielding radioactive liquid wastes of high salt content.

Solidification by chemical means was an alternative developed because of some of the difficulties of solidification with cement. The most common system is urea-formaldehyde (UF). The process consists of mixing UF and a catalyst (which are both liquids and stored separately) with an in-line mixer, and pouring this solution into a container of waste. Volumetric packaging efficiencies are generally in the range of 55 to 65 percent.

The mobile radwaste solidification systems operated by Chem Nuclear Systems, Inc., use urea-formaldehyde with in-container mixing. With this technique, air spargers are installed in the bottom of the disposable liner. The waste and UF are mixed in the liner using air. When thoroughly mixed, the acid catalyst is injected through the air sparger system to initiate solidification. It has been reported that the free water with this technique is generally limited to two to four percent.

Urea-formaldehyde would probably be in general use today had not a number of problems been encountered in the solidification systems developed to use this agent. Urea-formaldehyde is a condensation polymer system. As such, it should have been realized that water would be produced as one of the by-products of the polymerization reaction. However, many of the other difficulties only became apparent in the operation of actual systems. As a result, a variety of other processes are being developed or are already commercially available, albeit at significantly greater costs. These alternative processes are shown in Table 5-1.

Table 5-1. Chemical Solidification Systems for LLW.

Process	Key Features	Limitations
Generic Urea-Formaldehyde	Low viscosity permits use of in-line mixers	Free-water produced during polymerization
	Low cost for solidification	Waste released due to shrinkage of matrix
Dow Vinyl Ester Agent	High-quality product	Three-part mixture
	Wide-waste adaptability	Requires powered mixer
	Moderate equipment cost	Cost about 6 to 7 times UF
HITTMAN POLYPAC	Reduction of free water	Not commercially available
	Reduced matrix shrinkage	
	Direct replacement for UF	Cost about 3 to 4 times UF
WSU Polyester	Three-part mixture added as two parts	Requires further systems development
	High-quality product produced in laboratory tests	Requires moderate shear mixing
		Cost about 3 times UF

Bitumen immobilization is a one-step volume reduction and solidification process. It uses a screw extruder-evaporator to move free water, mix radioactive wastes with bitumen, and homogeneously disperse the wastes in a bitumen matrix. This waste solidification process is used to convert all particulate and wet wastes into a monolithic solid on a continuous processing basis. It is also used to encapsulate spent cartridge filters and similar small solid wastes that can be inserted into the waste containers prior to filling them with bitumenized wastes.

A facility has been conceptualized for the bitumen immobilization of fuel coprocessing facility wet wastes (Voss, 1979). The flow diagram for the Bitumen Immobilization Facility (BIF) is sketched in Figure 5-4. The facility is designed to be entirely remote in operation. The BIF contains eight major subsystems:

- Waste feed system.
- Bitumen feed system.
- Screw extruder-evaporator.
- Filling and capping stations.
- Inspection and decontamination stations.
- Container transfer cart.
- Bridge cranes.
- Control module.

Cement immobilization is a multi-step solidification process. The Cement Immobilization Facility (CIF) has been conceptualized for the solidification of TRU wet wastes from the Fuel Coprocessing Facility (Voss, 1979). The reference system functions by metering dry cement powder, a mixing weight, dry radioactive solid (if available), radioactive liquids and/or nonradioactive water into a drum. The metering step is followed by mixing the constituents by drum tumbling. A double fill process is specified to achieve maximum fill. The process produces a monolithic solid waste form for all fuel coprocessing facility TRU wet wastes. The flow diagram for the CIF is sketched in Figure 5-5. The facility is designed to be entirely remote in operation. The design uses concrete shield walls, four separate storage areas for segregating

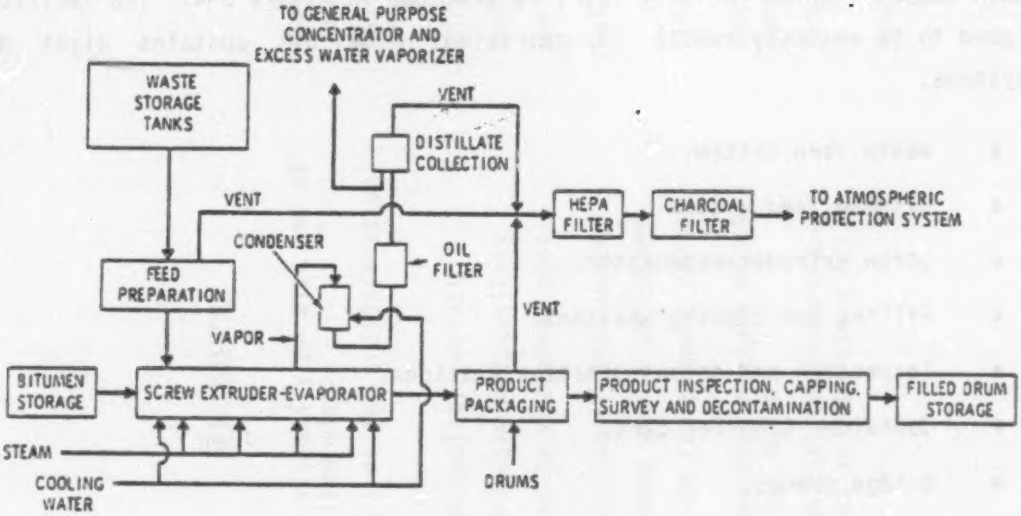

TO GENERAL PURPOSE CONCENTRATOR AND EXCESS WATER VAPORIZER
WASTE STORAGE TANKS
VENT
DISTILLATE COLLECTION
VENT
HEPA FILTER
CHARCOAL FILTER
TO ATMOSPHERIC PROTECTION SYSTEM
CONDENSER
OIL FILTER
FEED PREPARATION
VENT
VAPOR
BITUMEN STORAGE
SCREW EXTRUDER-EVAPORATOR
PRODUCT PACKAGING
PRODUCT INSPECTION, CAPPING, SURVEY AND DECONTAMINATION
FILLED DRUM STORAGE
STEAM
COOLING WATER
DRUMS

Figure 5-4. System Flowsheet for the Bitumen Immobilization Facility.

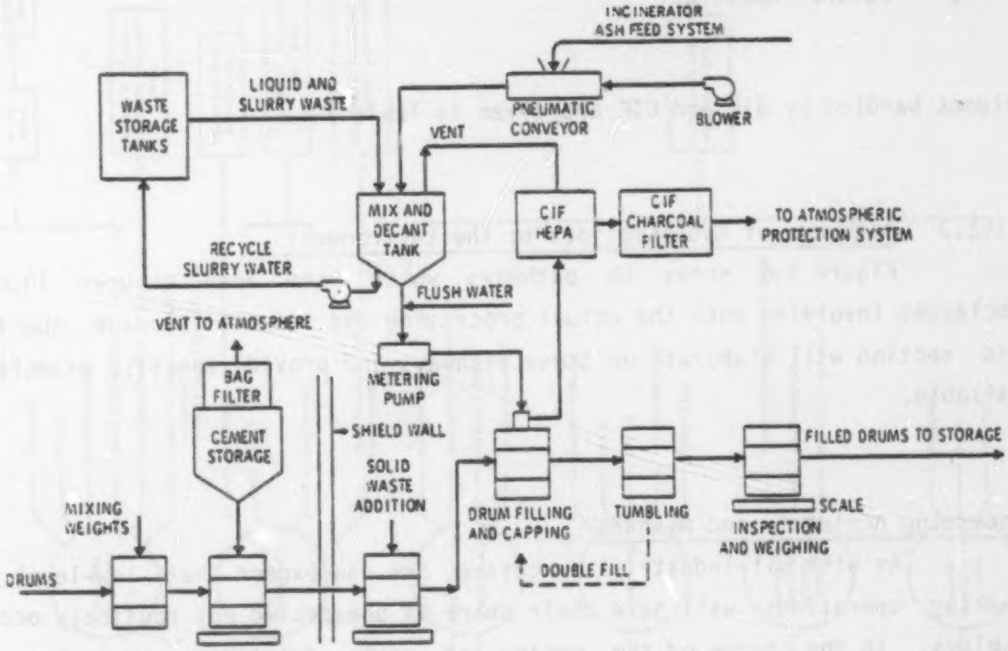

INCINERATOR ASH FEED SYSTEM
WASTE STORAGE TANKS
LIQUID AND SLURRY WASTE
PNEUMATIC CONVEYOR
BLOWER
VENT
MIX AND DECANT TANK
CIF HEPA
CIF CHARCOAL FILTER
TO ATMOSPHERIC PROTECTION SYSTEM
RECYCLE SLURRY WATER
FLUSH WATER
VENT TO ATMOSPHERE
BAG FILTER
METERING PUMP
CEMENT STORAGE
SHIELD WALL
SOLID WASTE ADDITION
DRUM FILLING AND CAPPING
TUMBLING
FILLED DRUMS TO STORAGE
SCALE
INSPECTION AND WEIGHING
MIXING WEIGHTS
DRUMS
DOUBLE FILL
SCALE
SCALE

Figure 5-5. System Flowsheet for the Cement Immobilization Facility.

wastes according to radiation levels and TRU content, and an enclosed truck bay. The CIF contains six major subsystems:

- Cement filling station.
- Waste feed system.
- Drumming station.
- Inspection and labeling station.
- Bridge crane.
- Control console.

Volumes handled by BIF and CIF are given in Table 5-2.

5.1.2.3 Pathways of Radionuclides to the Environment

Figure 5-6 shows 29 pathways which have been grouped into seven subclasses involving both the actual processing and interim storage operations. This section will elaborate on these pathways and provide specific examples when available.

Processing Accidents and Mishaps

As with all industrial processes, one can expect that low-level waste handling operations will have their share of unexpected but routinely occurring problems. In the course of the moving of waste from generators (especially institutions) to the burial site, several interim transfer and storage operations may occur. In the case of a university, transferring the wastes from laboratories to a central storage location and then on to final shipment may occur through a waste broker. In the course of these operations, misrouting could occur, especially if the wastes are shipped on common carriers. This misrouting could ultimately result in these waste packages being stored in warehouses, storage yards, or other facilities for extended periods of time, and could result in the release of radionucludes from failed packaging or direct exposure to facility personnel.

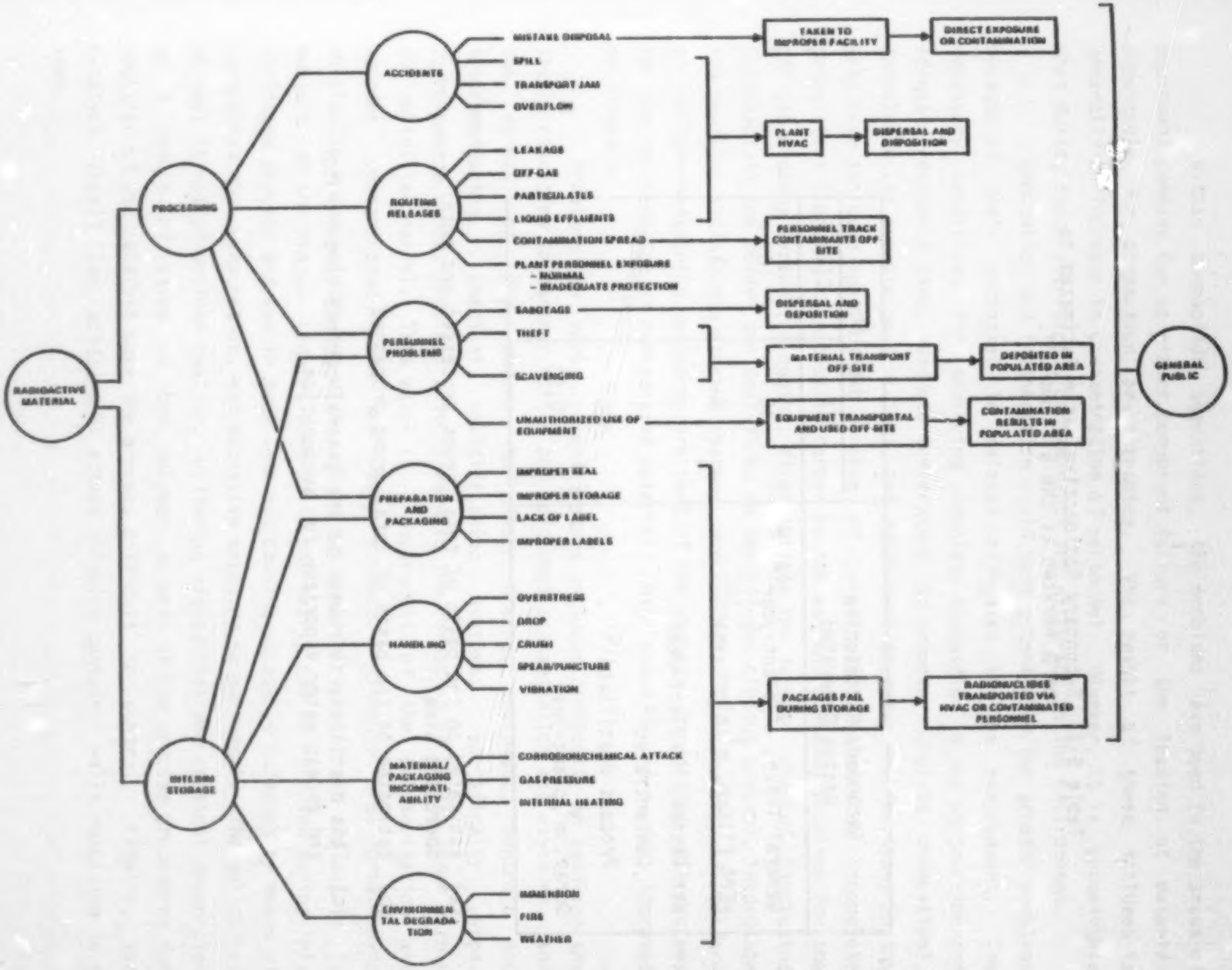

RADIOACTIVE MATERIAL
PROCESSING
INTERIM STORAGE
ACCIDENTS
MISTAKE DISPOSAL
SPILL
TRANSPORT JAM
OVERFLOW
ROUTINE RELEASES
LEAKAGE
OFF-GAS
PARTICULATES
LIQUID EFFLUENTS
CONTAMINATION SPREAD
PLANT PERSONNEL EXPOSURE
- NORMAL
- INADEQUATE PROTECTION
PERSONNEL PROBLEMS
SABOTAGE
THEFT
SCAVENGING
UNAUTHORIZED USE OF EQUIPMENT
PREPARATION AND PACKAGING
IMPROPER SEAL
IMPROPER STORAGE
LACK OF LABEL
IMPROPER LABELS
HANDLING
OVERSTRESS
DROP
CRUSH
SPEAR/PUNCTURE
VIBRATION
MATERIAL/ PACKAGING INCOMPATIBILITY
CORROSION/CHEMICAL ATTACK
GAS PRESSURE
INTERNAL HEATING
ENVIRONMENTAL DEGRADATION
IMMERSION
FIRE
WEATHER
TAKEN TO IMPROPER FACILITY
DIRECT EXPOSURE OR CONTAMINATION
PLANT HVAC
DISPERSAL AND DISPOSITION
PERSONNEL TRACK CONTAMINANTS OFF SITE
DISPERSAL AND DEPOSITION
MATERIAL TRANSPORT OFF SITE
DEPOSITED IN POPULATED AREA
EQUIPMENT TRANSPORTAL AND USED OFF-SITE
CONTAMINATION RESULTS IN POPULATED AREA
PACKAGES FAIL DURING STORAGE
RADIONUCLIDES TRANSPORTED VIA HVAC OR CONTAMINATED PERSONNEL
GENERAL PUBLIC

Figure 5-6. Pathways of Radionuclides to the Environment from LLW Packaging and Handling Operations.

Table 5-2. Secondary Radioactive Waste Estimated to be Generated at the BIF and CIF.

Secondary Radioactive Wastes Generated	Facility	
	BIF	CIF
General Trash, m^3/plant-year(a)	10	10
HEPA Filter, m^3/plant-year(b)	2	3.2
Wet Wastes, m^3/plant-year		
Concentrated(a)	1	1
Process Distillate(c)	560	-
Scrap, m^3/plant-year	0.03	-

(a) Estimated on the basis of total drums processed and total operating time.

(b) Estimated on the basis of total drums processed.

(c) This distillate is routed to the general purpose concentrator and excess water vaporizer for evaporation.

Within compaction operations, the problems have been in the areas of equipment jamming due to either component failure or the loading of material unsuitable for compaction or shredding. The result of these failures is generally an increase in contamination of personnel. However, it is conceivable that during these operations, contaminants are dispersed to the environment.

Combustion and incineration could pose potentially far greater problems because of their potential to release off-gases to the environment. The necessary conditions for achieving complete combustion in any incinerator are adequate residence time, adequate temperature (to promote complete combustion), turbulence (to promote good mixing), and sufficient oxygen. Problem areas in the past have included spalling and warping of construction materials, incomplete combustions (leading to excessive carbon in the ash and creating problems for the off-gas cleanup system), clogging, fires outside the furnace chamber (including flashback in the feeder and soot fires in the off-gas cleanup system), inadequate ash-handling and off-gas cleanup systems, and corrosion (particularly if sulfur- or halogen-containing compounds are part of the waste). Experience with systems for the incineration of radioactive materials has shown a need for improved performance.

Problems in early cement systems included difficulty in handling the slurry resulting in further spills and personnel contamination and exposure, and the spread of dry cement to floor drains, equipment, controls and instrumentation. Chemical solidification systems, specifically urea-formaldehyde, have problems associated with the formation of excess water within the solidified barrel. This water is a byproduct of the polymerization and becomes contaminated with the waste product. Although urea-formaldehyde physically encapasulates the waste, it is not chemically bound and the matrix is subject to shrinkage. Liquids tied up in the matrix can be released during this shrinkage process and can in turn leak out causing excessive releases by means of contamination, evaporation, and excessive exposure to personnel. The solidified product is not of uniform quality. Differing viscosities and chemical properties as a result of aging of the polymer as well as the precise procedures for addition of the catalyst make the process difficult to control. Finally, the catalyst itself (an acid) will attack shipping container walls resulting in a leak.

Effluent Releases

Normal LLW processing plant effluents vary according to the process and throughput. However, a conceptual design study performed at Pacific Northwest Laboratory (Voss, 1979) did include estimates for a Cement Immobilization Facility (CIF) and a Bitumen Immobilization Facility (BIF).

Effluents fall into two categories: direct and indirect. Direct effluents are mainly airborne radionuclides resulting from waste processing as well as secondary radioactive wastes such as miscellaneous decontamination solutions and contaminated scrap materials (metal, paper, etc). Indirect effluents include heat generated in waste processing which is typically dumped to the atmosphere via a secondary cooling system, and radioactive effluents from treating secondary radioactive wastes.

Direct airborne effluents of the BIF and CIF are estimated to be identical at $1x10^{-9}$ of the input radioactivity, except for tritium and iodine. An additional decontamination factor of 10^4 is assumed for the particulate radionuclides prior to release because of atmospheric protection system filtration. An estimated $1x10^{-4}$ of the radioiodine is released to the plant atmospheric protection system from both processes. An equal fraction of tritium is estimated to be released in the CIF, while nearly 100 percent of the tritium is released in the form of evaporated water from the BIF.

In addition to gaseous effluents, volume reduction operations such as shredding or incineration may lead to the release of particulates, especially in the event of a partial failure of the filtering system (although this may be considered an accident rather than a routine release). Liquid effluents include those released to sewers by institutions as part of their normal disposal practice of very short-lived nuclides. Depending on the process, other liquid effluents may be released from LLW processing centers at fuel cycle facilities. Despite precautions at radiation facilities, it is possible that personnel will track contamination out of the plant. This may also be true of vehicles, especially if they have transported poorly-packaged waste. Exposure of plant personnel in the course of processing the waste material will be dependent on the process used and the nature of the facility. In the case of a reactor (Buring and Gutwein, 1979), exposures on the order of 30 person-rems per year. Excessive exposures would occur in the event of inadequate shielding, equipment, clothing, or operating procedures.

Personnel Problems

A potential class of pathways from the LLW operations to the public is by means of deliberate actions on the part of operating personnel. The most obvious of these is sabotage. There has already been an instance of sabotage-related activity at the Surry nuclear power station. A related activity is the theft of LLW from the site with malicious intent for political or other reasons.

A seemingly more innocuous activity is the scavenging of otherwise useful equipment from the waste site. Incidents have been reported where military radium-painted gauges have been removed from the Beatty site. Misuse of contaminated plant equipment has also resulted in exposure to the public. In the case of the Beatty site, a cement mixer used for solidification of liquid radwaste was also used for pouring concrete for surrounding residential and public structures.

Preparation and Packaging Problems

In addition to process and personnel-related problems, there are those connected to the quality control of the outer packages in which the wastes are stored. These include improper closing and sealing operations (which may be quite involved in the case of large quantity wastes), improper or inadequate storage conditions, or the lack of an adequate label which would prevent the package from being opened and result in release to the public.

Handling Problems

In the course of moving the radioactive material through the various interim storage locations between the point of generation and the final burial, numerous handling operations occur. Generally, these involve the use of cranes, forklifts, and other machines which can inflict considerable damage on the package and result in a potential for release. Thus, it is possible that the package will be overstressed due to improper handling or a bad storage configuration, dropped, crushed, speared, or punctured. It is also possible that vibration in the course of its movement through the various waste handling facilities will cause package failure.

Material/Packaging Incompatibility

A poor choice of packaging material may result in a chemical interaction between it and the waste with a resultant leak or spill that could ultimately affect the general public. These interactions may consist of corrosion, the generation of gases, or other problems. Gases generated from the waste and internal heating must also be taken into account in the package design and can result in breaching packages in some circumstances. Subsequent to package failure, radionuclides can be released to the surrounding environment either during transportation or via the building HVAC system.

Environmental Degradation

The storage of wastes in poor environmental conditions will result in their release from the packages. Should the wastes become submerged during their storage, or be in a fire, then it is probable that some of their radionuclide inventories will reach the surrounding environment. There are more subtle pathways as well. In the event that these wastes are stored out of doors (as in the case of a Chem-Nuclear site at Arlington, Oregon), rainwater may cause some leaching and animal activity may cause significant transport of radionuclides.

5.1.3 Transportation Pathways

To date, wastes have been shipped almost exclusively by truck with occasional shipment by rail. This will very likely continue to be the case for low-level waste, with the choice of transport mode dependent on convenience and economic considerations. Some nuclear power plants are on navigable water, but burial grounds are usually not. However, it is possible that shipment part way by boat or barge will in some cases be economical. Truck transport is highly versatile, and the only significant potential problem now foreseen from the equipment standpoint is providing adequate tiedown. It has been observed that heavy containers are sometimes not tied down securely enough to withstand bad road conditions or minor accidents. Tiedowns apparently must be several times stronger for railcars than for trucks, in relation to package or cask weignt, because of the large accelerations imparted to railcars during coupling operations.

The number of radioactive material shipments per annum is estimated to be about one million, of which 50,000 are Type B (McCluggage, Unpublished) (U.S.A.E.C., 1974). During the past few years there have been many more incidents involving packages damaged in handling or being run over at terminals than incidents involving vehicle accidents. Although many packages containing Type B amounts of radioactivity have been involved in accidents, none has as a result released a detected amount of radioactive material. There have, however, been a few cases of partial escape because of a faulty packaging procedure rather than accident. The possibility of a large release from Type B packages in very severe accidents is a matter of primary concern. There have so far been eight or ten accidents with Type B packages that might be considered severe, and no release or excessive external radiation level resulted.

Type A packages are not designed to withstand severe accidents and, therefore, occasional accidental release can be expected. At the same time, the amount of radioactive material is so small that no serious consequence is expected. Soft waste material generated at nuclear reactors and associated fuel cycle facilities, (e.g., contaminated paper and clothing) are compacted and typically placed in 210-liter drums for shipment. Each drum may contain 230 kg of compacted material with up to one curie of activation and fission products. The low specific activity and low radiation levels allow the contaminated trash to be shipped without shielding. Because the radioactive contamination is bound on the compacted material, it is unlikely to be released in the event the drums are broken open by accident or criminal acts. Even if an entire truckload of 50 drums were to be consumed by fire, the amount of radionuclides that would become widely dispersed would be quite small. It has been estimated that as much as 99 percent of the 50-curie inventory would remain in the ashes, and only one percent (primarily Cesium-137) would become airborne (U.S.A.E.C., 1972).

Liquid fuel cycle and reactor wastes such as contaminated resins and sludges are dewatered, consolidated by mixing with concrete (or other solidifying agents), and typically placed in 210-liter drums. The majority of these drums contain less than 20 curies and are shipped as Type A packages. A small percentage contain up to 100 curies (20 curie average) and are shipped as Type B packages. The cemented, solidified form of the waste materials contributes significantly to the retention of the radioactive inventory in case of container failure. If each container of a 50-drum Type A shipment of cemented wastes were broken open by acts of sabotage, the total activity released to the atmosphere would be quite small. Approximately $2x10^{-3}$ curies of gaseous and volatile fission products would become airborne (U.S.A.E.C., 1972).

It would be extremely difficult to breach the Type B package to the extent of breaking open the inner container and exposing the solified wastes. In the unlikely event this were to occur, approximately 0.2 curie of fission products (primarily Cesium-134 and -137) would be released to the atmosphere for each 210-liter drum ruptured (U.S.A.E.C., 1972). For a 42-drum load, which would probably be the limit for a Type B truck shipment, the total activity released would be 8.4 curies. Because of the form of the material, it is unlikely that the presence of an open fire would significantly increase the activity that would become airborne. The breach of the Type B package and the exposure of the cemented wastes would contaminate the transport vehicle and nearby ground and produce a radiation field. However, the hazard would be limited to the vicinity of the vehicle.

Quantities of low-level radioactive waste exceeding Type A limits (high intensity) must be shipped in Type B packaging. Type B packaging must be designed to withstand normal transport conditions without loss of contents or shielding efficiency and to suffer no more than a specified loss of contents or shielding efficiency if subjected to the following specified sequence of accident-damage test conditions: impact, puncture, fire, and (for fissile material) immersion in water. Type B packages and large-quantity packages must survive a series of tests designed to simulate the damage that might be expected in a severe accident situation. According to the regulation, survival means that (1) the shielding is not damaged in such a way as to allow radiation leakage of more than one rem/hr at a distance of 0.9 meters from the package and (2) no material is released from the package except for very limited amounts of gases and coolants.

There have been numerous collisions of trucks with private automobiles and derailment of railcars, which as it turned out posed no threat to the cargo. There has apparently been no accident that subjected a Type B container to the most severe impact that it is designed to resist, but there have been one or two fires approaching the design value. Because of the form of the materials and the relatively low levels of radioactivity, low-level wastes are considered unlikely targets for sabotage. Even if subjected to criminal acts, no major hazard would result.

Radionuclide release mechanisms as a result of transportation are depicted in Table 5-3. As previously mentioned, perhaps the most significant cause of accident is insufficient cargo tiedown resulting in vibration or loss of load. Transport mechanisms of released radionuclides are also shown in Table 5-3. While there are many potential release and transport mechanisms, the resultant hazards are not considered to be severe because of the relatively small amounts of radioactivity involved.

5.1.4 Maxey Flats Pathways

There are four general pathways that potentially could result in exposure of the public or the employees at the burial site to abnormally high radiation levels. These pathways include:

- Radioactive particles that may become airborne during receiving, processing, burial, or post-burial activities at the site.
- Radioactive materials that may be leached from the wastes during or after burial by the action of groundwater or by dispersion of the radioactive isotopes into underlying aquifers. These contaminated waters may then be used by people directly or be taken up by plants or animals that eventually become a portion of the food chain.
- Improperly or inadequately shielded radioactive materials resulting in direct exposure of the public to ionizing radiation, or more likely, exposure of burial ground operating personnel.
- Radioactive contamination off-site through release of improperly cleaned vehicles or by removal of salvageable materials from the burial ground during or subsequent to the active phase of the operations.

These pathways are shown in expanded form in Table 5-4.

The Maxey Flats burial site has been closed since 1977. The possibility of the site being reopened for acceptance of waste appears to be very slim. The site was closed because of controversy concerning its effects on the surrounding environment. As early as 1971, it was decided studies were needed to ensure that precipitation that infiltrated completed trenches would not result in contamination of the groundwater. The basic problem at Maxey Flats is that the basal unit of the trenches is the tight, impermeable Farmers Member of the Borden Formation. Because of the impervious nature of this layer, water that infiltrates the trenches will collect in the trenches. During periods of abundant rainfall, waste in the trenches may actually be surrounded by water. An

Table 5-3. Radionuclide Release and Transport Mechanisms Due to Transportation of Waste.

RELEASE MECHANISMS (TRUCK-TRAIN-BARGE)

(1) Accident - Driver error, mechanical problems, heavy load, poor road conditions (weather), poor tiedown (loss of load, vibration), collision with another vehicle or obstacle, barge sinking or grounding, train derailment

(2) Leaking - Inadequate package or seal, excessive waste or package temperature or pressure, inadequate shielding, contaminated package or vehicle, fire, explosion

(3) Personnel - Sabotage, hijack, theft, neglect

TRANSPORT MECHANISMS

(1) Air Dispersal - Wind, fire, explosion

(2) Water Dispersal - Groundwater transport, food cycle, immersion

(3) Personal Exposure - Direct radiation dose, ingestion, inhalation

(4) Environment - Absorption by soil, flora and fauna, food cycle

Table 5-4. Radionuclide Release Paths — Burial Operations.

OPERATIONAL ELEMENT	RELEASE MODE	PRINCIPAL PATHS TO BIOSPHERE/MAN
Package Acceptance	Leaking packages	Direct exposure, spread by vehicles/personnel
	Hot Load (mislabeled)	Direct exposure
Equipment	Contaminated vehicle	Direct exposure, spread by vehicle/personnel
	Decontamination of vehicles	Wind (suspension) Direct exposure Water contamination
Handling/Packaging	Package rupture due to: • procedure violations • operator error • equipment failure • sabotage • explosion	Wind born Water path Direct exposure (inhalation or injection)
Trench Emplacement	Crushing Compaction Gas venting	Windborn Water Direct exposure (inhalation or injection)
	High radiation level	Direct exposure (shine)
Uncovered Waste	Fire Sabotage Theft Explosion Animal intrusion Weather	• Wind born • Direct exposure • Food chain • Water
Post-Burial Administrative	Water intrusion and leaching Corrosion Animal intrusion Earthquake Flood Storms Erosion	• Wind born • Water • Food chain • Direct Exposure
Post-Burial Limited Use	Human intrusion (excavating) Corrosion Animal intrusion Earthquake Flood Storms Water intrusion & Leaching Erosion	• Wind born • Water • Food chain • Direct exposure

example of the properties of trench water samples taken at Maxey Flats is given in Table 5-5.

At present the water is pumped out of the trenches and processed via a continuous evaporation unit. The use of the evaporator at Maxey Flats releases small amounts of tritium into the atmosphere. Traces of other radionuclides may be released. Evaluation of the tritium release has shown that acceptable doses are released to the general public. Any resulting residue from the process will be disposed of properly, most likely by burial.

Because of the suspension of commerical operation, the main pathways of radionuclide release are those shown in Table 5-4 that are not related to the operating phase. The radionuclide release pathways of main concern are the release via the evaporator unit plume and the migration of radionuclides via the water. The second pathway is the most serious and by far the most complex. The potential mechanisms through which radionuclides may be released from Maxey Flats via water include (1) transport of dissolved nuclides to wells, gaining streams, or springs and (2) transport upward through the soil via capillary flow. Both mechanisms allow the transfer of radionuclides to the biosphere. The processes that control transport of solutes in hydrogeologic systems include (1) convection by a moving fluid, (2) hydrodynamic dispersion, which combines the effects of mechanical dispersion and molecular diffusion, and (3) chemical reactions which take place between various solutes, between solutes and the solid matrix of the system, and within the solute, such as radioactive decay.

The hydrogeology at Maxey Flats is poorly understood. A good discussion of the potential pathways of release via groundwater has been published (Papadolpulos and Winograd, 1974). The discussion will not be repeated here and the reader is referred to the reference for more detail.

5.1.5 Barnwell

The Barnwell site, as is the case with all other operating sites, has the potential for exposing selected segments of the population via the pathways listed in Table 5-4. To date the impact of Barnwell on the surrounding environment has been undetectable from a radiological point of view. Potential impacts are discussed in the following paragraphs.

Table 5-5. Ranges of Values of Selected Properties of Trench Water Samples from Maxey Flats, Kentucky, Disposal Site, 1977 (Robertson 1979).

PROPERTY	RANGE OF MEASUREMENTS
pH	2.2 - 12.4
Specific Conductance (micromhos/cm at 25°C)	$4.0 \times 10^2 - 3.9 \times 10^4$
Dissolved Organic Carbon (mg/1)	$< 1 - 5.8 \times 10^3$
Gross Alpha (pCi/1)	$< 1 \times 10^2 - 6.4 \times 10^5$
Gross Beta (pCi/1)	$8.3 \times 10^2 - 5.7 \times 10^7$
Gross Gamma (relative cpm)	$< 10 - 1.6 \times 10^4$
Tritium (pCi/1)	$2.5 \times 10^5 - 7.4 \times 10^9$
Am-241 (pCi/1)	$< 1.7 \times 10^2 - 4.7 \times 10^3$
Cs-137 (pCi/1)	$< 1.5 \times 10^2 - 9.2 \times 10^4$
Co-60 (pCi/1)	$< 20 - 8.4 \times 10^5$
Bacteria	Aerobes and anaerobes abundant in most samples

The exposure of the working force at the site is monitored and, therefore, is the easiest pathway to discuss. Table 5-6 illustrates average occupational exposure at Barnwell during 1978. Exposure levels should remain the same in the future unless an unforseen event dealing with high exposure rate waste should take place.

A possible exposure pathway at Barnwell is from the sandblasting facility located in a trench. It is possible activity could be carried off-site given certain weather conditions. However, a permanent sandblasting facility is being built and this potential pathway will be eliminated.

Other potential pathways during operation include windblown activity from damaged waste packages. Also, weather occurrences could result in transport of radionuclides and waste forms off-site. An example is a tornado that hits the site and carries away exposed waste.

The potential pathways via goundwater transport are not similar to Maxey Flats because water does not tend to collect in the trenches except during periods of extremely heavy rains. Therefore, the potential for leaching nuclides is much lower than at Maxey Flats. Samples of trench water have generally had much lower concentrations of radionuclides.

In general, the pathways at Barnwell are similar to those at other sites with the differences in local meteorology and geology being the differentiating factors for the site.

5.1.6 Beatty

The site specific operating and geophysical characteristics at the Beatty burial ground may influence the importance of the pathways shown in Table 5-4 in contributing to the potential exposure of operating personnel or the general public to radioactive materials. These site characteristics are discussed in the following paragraphs.

All shipments to the Beatty burial ground are made by vehicles operated and controlled by other parties. Consequently, the burial ground operating management has no direct control over the condition of shipments or waste containers that arrive at the site for disposal. The site is operated on the presumption that the vehicles and the waste containers have been properly handled and that the federal and state ordinances and regulations regarding the packaging and transport of radioactive materials have been satisfied. The site management

Table 5-6. Occupational Exposure at Barnwell, 1978 (Ebenback, 1979).

CATEGORY	NUMBER	EXPOSURE mR/month
H.P. Techs.	4	198
Office, Mgm., Supv. (Includes Dispatcher, Janitor, Warehouseman)	9	26
Offloaders	15	174
Truck Drivers	8	21
Equipment Operators	6	176
Maintenance Personnel (Mechanics, Welder, etc.)	6	6

does reserve the right to refuse delivery of materials or vehicles that do not satisfy the stated conditions. This right of refusal is seldom exercised as it is recognized that remedial actions to correct any deficiencies and to prepare the waste materials properly for burial are preferable to refusing delivery of a substandard shipment or package. If the shipment were refused, then a potentially hazardous shipment would be forced to travel considerable distances over the public roads before remedial actions could be undertaken. In those instances in which improper or damaged containers have been discovered during unloading operations at the site, the radioactive materials have been repackaged by site personnel and then buried following standard disposal procedures. No other packaging or waste processing activities are normally performed at the Beatty site.

Only one burial trench is open at a time at the Beatty site. Emplaced waste is covered periodically with backfill depending on the rate of receipt of waste materials. The waste is covered on Friday afternoon prior to the normal weekend shutdown.

The waste burial procedures regarding depth of backfill and control of airborne ractioactivity have been devised such that no credit is taken in radioactive release calculations for the integrity of the waste packages or containers. Consequently, the procedure normally used for emplacing waste in the trench is to roll or tumble the waste containers down a ramp located at the active end of the burial trench. Very heavy or bulky containers can be hoisted into position at the bottom of the trench using a crane if the normal tumbling procedure is considered impractical. If waste packages or containers are breached during emplacement operations, then the waste is monitored. If the quantity exposed is higher than procedural limits, emplacement activities are discontinued and the exposed wastes are buried.

The practice followed at the Beatty site after unloading is to monitor each vehicle leaving the facility for traces of radioactivity. If a vehicle is found to have ionizing radiation levels in excess of natural background, the vehicle is decontaminated using high pressure steam. If the contamination cannot be removed by steam cleaning, then the affected portions are stripped from the vehicle and are buried at the site. This procedure is effective in preventing the inadvertent spread of radioactive materials when the vehicle is returned to service hauling general cargoes.

The Beatty burial ground is located in an extremely arid region that extends tens of kilometers in all directions from the site. Because of the combination of lack of appreciable precipitation and specific soil characteristics, the probability is very low that radioactive isotopes would be leached from the buried wastes by intrusion of surface or ground waters into the wastes. Also, the lack of surface waters that could serve as a transport mechanism precludes migration of radioactivity from the waste trench to the aquifer underlying the site at a depth of about 175 meters. These tentative conclusions are substantiated by the fact that no surface waters have been detected in any of the test wells on or surrounding the active portions of the burial site.

There is very little vegetation at the Beatty site. As a consequence, erosion of the ground surface by the wind after the waste is buried and the site is closed is a possible method for removing the soil cover and exposing the wastes. The soil material is a mixture of sand and gravel. When the surface is disturbed by the wind, the light sandy fraction becomes airborne. The gravel is too heavy to be displaced and the gravel fraction predominates at the exposed surface. This condition is termed "desert polish" and the material becomes stable when the light fraction has been removed from the top inch or two of the original surface soil. Further gross disturbance is necessary before more erosion could occur.

The Beatty site is typical of much of the land in the vicinity. The natural rainfall is not sufficient to allow the area to be used for farming or grazing. Mining and mineral extraction are the only activities that are practiced within several kilometers of the site. These activities are not likely to occur at the Beatty burial ground. In developing the site, a well was drilled to bedrock about 175 meters below the surface. Well sample studies indicated that the mixture of sand, gravel, and clay persisted through the entire distance. No minerals were discovered that have commercial value or are not typical of the materials found at other sites in the vicinity. It is considered improbable that the Beatty burial site or nearby area would be selected for any use other than a burial site in the forseeable future.

5.1.7 Richland/Hanford

The characteristics of the Richland shallow land burial sites (NECO/DOE sites) are generally favorable for safe burial of solid radioactive wastes. Factors which make the sites favorable include limited rainfall and high solar heat input which result in a high deficiency of soil moisture in the soils and sediments. Another favorable factor is the depth to the watertable. As a consequence, meteoric water does not percolate to the watertable in most areas, but rather enters the ground to a maximum depth of two to four meters where the water is held by strong capillary forces. Moisture is then slowly returned to the atmosphere via evapotranspiration. In this environment, the potential for dissolution and transport of radionuclides from dry wastes by meteoric water is small especially since leaching is dependent on water volume. Under these conditions, surface runoff is negligibly small. Limited local runoff and ponding may occur during periods of rapid snowmelt over frozen ground; however, deep erosion of burial grounds by this mechanism is unlikely (Gerger, et al, 1977).

Solid wastes contaminated with radioactivity have been disposed of by shallow land burial at the Richland-DOE site since 1944, and at the NECO site since 1965. Burial grounds in the 100 and 300 Areas (DOE) are relatively close to the Columbia River and are mainly underlain with permeable materials. Depth to water varies from about five to 25 meters. Burial grounds located on the 200 Areas plateau are underlain by considerable thicknesses of low permeability materials. Wastes buried here are 70 meters or more above the watertable. Vadose water movement beneath these burial grounds has virtually undetectable flow and the soil has a large capacity for ion exchange, which will remove and retain radionuclides. Since 1973, essentially all of the solid waste generated at Hanford has been stored or buried in the 200 Area.

In addition to possible groundwater transport of released radioactivity, there is limited potential for other radionuclide transport pathways as shown in Table 5-4. The most broadly distributed vegetation type is sagebrush/cheatgrass. Deeply-rooted plants such as tumbleweed, sagebrush, and rabbitbrush accumulate and concentrate certain radionuclides. Deciduous shrubs and herbaceous plants provide valuable food and nest sites for game and summer forage and cover for mule deer. The mule deer is the only big game mammal normally found near the burial sites, living mostly along the Columbia River with smaller concentrations near the 200 Areas. The cottontail rabbit is the most abundant small game mammal with a small population scattered throughout the entire area. Other mammals present in appreciable numbers include the raccoon, beaver, muskrat, mink, porcupine, badger, and coyote. Small mammals are abundant, particularly the Great Basin pocket mouse. Deer mice, ground squirrels and pocket gophers are also abundant.

There is limited potential for animal intrusion into buried wastes. The ground squirrel digs a burrow up to one meter deep while the badger digs a burrow up to three meters deep. However, both animals are scarce in the 200 Area plateaus. Problems of radionuclide transport by other animals (birds, snakes, lizards) or insects could arise if deeply-rooted plants were permitted to grow or if the soil cover was so thin that grass roots could penetrate to a depth where contaminated sediments are present. Radionuclides could subsequently be carried to the surface, making them available in food supplies. This problem probably constitutes the greatest long-term threat of transporting radionuclides into the uncontrolled environment.

Less likely causes of radionuclide release and transport are natural phenomena. No credible natural forces event other than major flooding by the Columbia River can be postulated that will release a significant amount of radioactivity from the groundwater or ground storage sites. Forces such as those resulting from seismic activity, heavy rains, heavy snowmelt, tornadoes and high winds are considered to be inconsequential. Based on a ten-year record, an average of twelve fires per year have occurred over a median area of about six acres. The largest fires have originated from lightening strikes. Because of limited vegetation and standard procedures for covering waste, the amount of combustible waste that might be ignited is limited.

Other potential release/transport mechanisms of buried waste are those classified as human intrusion. Examples of such are drilling, exploration, farming, recreation, and exhumation. The remaining sources of radionuclide release and transport pertain to unburied waste and consist of facility operating procedures and practices. Radioactive waste packages may be "hot" (off-specification, mislabeled) or leaking upon arrival. In addition, equipment such as the truck or other handling equipment may be contaminated. If decontamination is attempted, procedures may result in dispersal of radioactive materials. There are many instances in which rupture of the waste package could occur during handling activities. Examples of such are accidents due to operator error, procedures violations, equipment failure, sabotage, and explosion. For

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example, at the Richland-DOE site, there is occasional above-ground release from filter systems associated with the caisson method of disposal of TRU waste.

Since much of the handled waste material is very low-level waste, packaging may not be designed for containment after emplacement in the trench. Releases may occur during handling prior to emplacement or after emplacement and prior to or during the burial procedure. There are many mechanisms by which uncovered waste may be released. Examples of such include fire, sabotage, theft, explosion, and animal intrusion. In many cases, normal weather conditions will result in release and/or dispersion of radioactive nuclides. Crushing or compaction of waste packages during burial procedures will also result in significant radionuclide release.

5.1.8 West Valley

Commercial burial operations were begun at West Valley, New York, in 1963, and voluntarily terminated in the spring of 1975, because of radioactively contaminated water seepage from two burial trenches. Approximately 67,000 m^3 of waste containing about 580,000 curies of radioactivity was buried. Burial operations consisted of the receipt, temporary storage, burial in trenches of packaged radioactive wastes, and continuous monitoring of the radioactive characteristics of the surrounding ground, air, and water. The packages were normally buried as received with no reprocessing or repackaging of the contents. In some cases, the primary package containing the wastes was shipped in a reusable overpack or secondary container, and in these instances the primary package was removed from the reusable overpack before burial. The purpose of the packaging was to provide ease of handling, minimize personnel exposure, and prevent spread of the radioactive material to the environment prior to burial. Credit was not taken for containment provided by the packages once they were buried.

During 1973 and 1974, a study was undertaken to determine the extent of any migration of radionuclides from existing trenches (Jump, 1976). Based on measurements of soil ion exchange capacity prior to the commencement of operations, it was known that most radionuclides were sorbed by the soil. Therefore, tritium, which has no affinity for the soil, was chosen to determine the extent of migration. Results of the study showed some evidence of tritium migration adjacent to trenches that contained water. However, the concentrations of tritium were very low. Trench water samples were found laden with various organic solutes, radionuclides, and other inorganic solutes. Laboratory studies of the soil revealed excellent sorption characteristics for many of the other radionuclides.

In 1975, it was discovered that high water levels in burial trenches had resulted in formation of surface seeps. The state had noted increased levels of tritium in water samples taken from on-site monitoring stations. The seepage resulted from the compaction of waste and the filling up of the trench with water and subsequent seepage through the low end of the trench. An investigation was begun to determine the extent and pattern of migration of waterborne radionuclides from trenches and to identify the geohydrologic characteristics that influenced such migration. In the course of the investigation, two sources of accumulated water were identified (1) infiltration of precipitation through the trench soil cover and (2) to a much lesser extent, groundwater movement from adjacent silty fill. As a result of this radionuclide migration, operation of the West Valley site was suspended until such time that requirements for operation of the site were met and agreed to by the state. To date, no agreement has been reached and the site remains closed.

In addition to the precipitation infiltration and groundwater mechanisms for radionuclide release and migration, potential for other mechanisms existed as depicted in Table 5-4. Typical operation at West Valley upon receipt of a waste shipment included scanning of packages with a radiation survey meter, smear testing, if surface contamination was suspected, and special handling when necessary for safety. Trucks and major site equipment were monitored after each use that involved exposure to radioactive materials and were decontaminated, if necessary, before further use.

At humid disposal sites with relatively high rainfall and low evaporation, such as West Valley, infiltration of surface water can cause buried wastes to be completely submerged in extreme cases. The combination of high rainfall and impermeable soil makes it necessary to be especially efficient in operational measures to exclude water from the trenches. Leaching of radionuclides from buried wastes may be caused by removal of material from the surface of contaminated waste containers or, ultimately, by the soaking and dissolution of radioactive contents from inside the containers.

5.1.9 Sheffield

Commercial burial operations were begun at Sheffield, Illinois, in 1967, and terminated in 1977, when its licensed area became filled. Approximately 74,000 m^3 of waste containing about 50,000 curies of radioactivity was buried. The burial site is located in a rural area utilized mainly for forage and pasture and adjacent to land previously strip-mined and returned to pasturage by a coal company. The site itself was not disturbed by mining operations. Soil permeability is such that accumulation of water in waste-filled trenches is generally prevented, except during periods of heavy rainfall and rapid snow-melt such as happened in the spring of 1979. Groundwater gradients through the site are such that water leaving the site moves toward the adjacent strip-mined land at calculated rates of movement of three to 15 mm/day. At this rate, travel time to the closest surface-discharge point for groundwater is calculated to be 125-150 years.

Of particular interest and difficulty at Sheffield is the analysis of unsaturated flow regimes from the trenches to the watertable. Water from wells up to 23 meters from the downhill side of trench 11 have shown gross beta activity and tritium concentrations well above background (up to 40,000 pCi/l). A down-hole gamma spectrum log run on a well within three meters of this trench indicated the presence of Co-60 in one zone. During excavation, elevated tritium activity was detected in samples collected directly beneath the trench within three meters of the trench floor.

As with all of the other commercial burial sites, various radionuclide release and migration mechanisms existed during all phases of operation at Sheffield. These general mechanisms are shown in Table 5-4.

5.1.10 Reference Site

There are three principal pathways through which radiological exposure may result from the shallow land disposal of low-level waste at a reference site. They are inhalation, ingestion, and direct exposure. The direct exposure pathway is of significance primarily to workers involved in the actual disposal and, to a lesser extent, the transportation of LLW. The inhalation and ingestion pathways may be of significance to both the general public and occupationally-exposed individuals. The events and subpathways that may lead to exposure through any of the three principal pathways are numerous and varied, and were listed previously in Tables 5-4 and 5-7.

It should be noted that the pathways for the reference wet and dry sites are essentially the same. The major difference between the two sites is associated with the relative magnitude and significance of radionuclide leaching and soil movement resulting from interaction with water in the soil.

5.2 DEVELOPMENT OF SCENARIOS

This section contains the discussion of the methodology used in deriving release scenarios and source terms for these scenarios. Following the description of the methodology in Subsection 5.2.1, the phases of LLW management activities to which release scenarios apply are identified in Subsection 5.2.2. The initiating events (IEs) are the starting points for the development of release scenarios and are described in Subsection 5.2.3. The radionuclide content of various types of wastes, their packaging, and physical properties are important parameters in the calculations of the magnitude of release. They are described in Subsection 5.2.4. Finally, examples of representative release fractions (RFs) for chronic and accidental release scenarios are described in Subsection 5.2.5.

5.2.1 Scenario Development Methods

This subsection summarizes the methodology for the derivation of events that result in the release of radioactive isotopes from low-level waste (LLW) management activities. The isotopes released to the environment enter pathways which may lead directly or indirectly to the exposure of site workers or the general public. The release events may occur during any activity in the various phases of the LLW management cycle (i.e., from generation, through burial and limited public use of the disposal site). The significant phases of the LLW management life cycle are illustrated in Figure 5-7 and described in Subsection 5.2.2.

The representative radionuclide release scenarios are summarizese Volume 3, Appendix C. These scenarios were derived using a modified version of the event tree methodology developed in the Rasmussen reactor safety study (NRC 1975). The event tree methodology was modified to matrix format to accomodate

Table 5-7. Reference Site Subpathway Leading to Inhalation or Ingestion.

1.0 Releases to Air
- direct inhalation
- cloud submersion
    - plant foliar retention/ingestion
- soil deposition
    - resuspension/inhalation
    - plant uptake/ingestion
- surface water deposition
    - drinking water/ingestion
    - irrigation/ingestion

2.0 Releases to Soil
- migration toward surface
    - resuspension/inhalation
    - plant uptake/ingestion
- migration toward water
    - drinking water/ingestion
    - irrigation/ingestion

3.0 Releases to Water
- drinking water/ingestion
- irrigation/ingestion

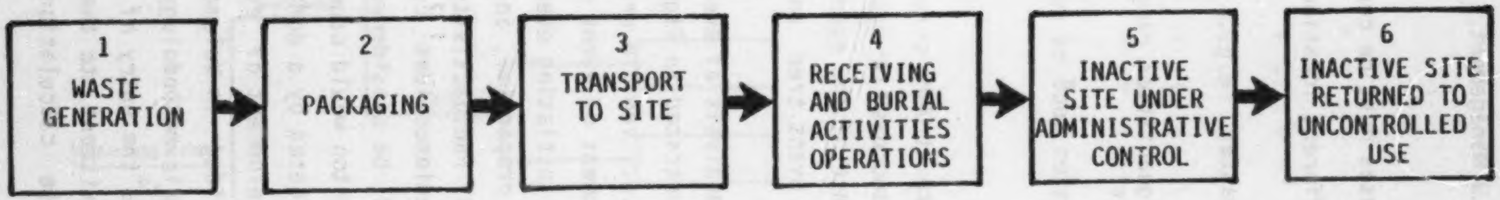

1
WASTE GENERATION
2
PACKAGING
3
TRANSPORT TO SITE
4
RECEIVING AND BURIAL ACTIVITIES OPERATIONS
5
INACTIVE SITE UNDER ADMINISTRATIVE CONTROL
6
INACTIVE SITE RETURNED TO UNCONTROLLED USE

Figure 5-7. Low-level Waste Management Activity Phases

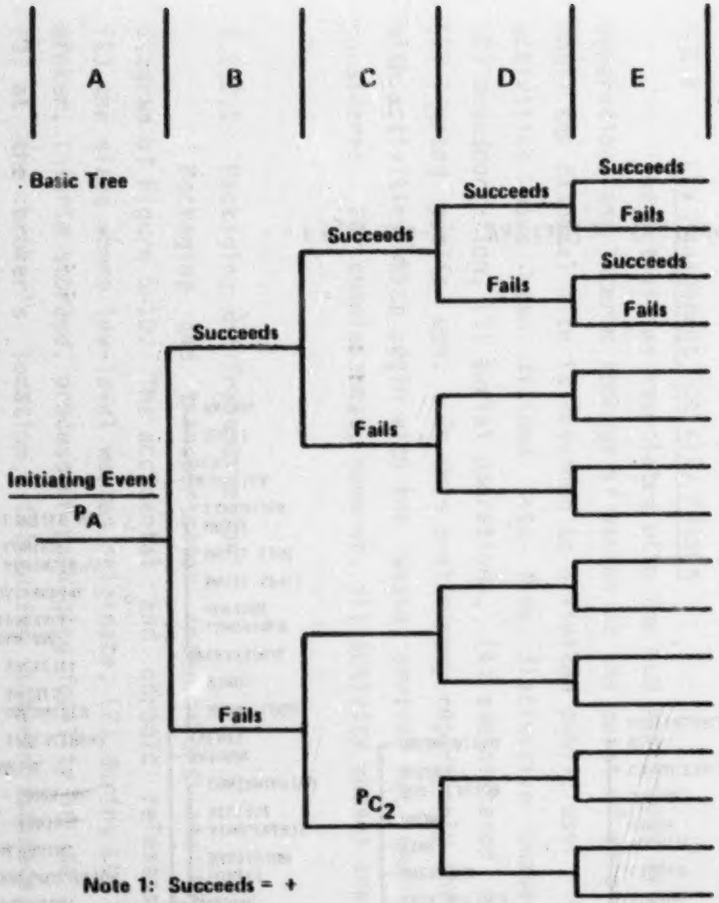
the large number of variables which must be used to develop sequences leading to fully characterized release scenarios in LLW management. These variables include the following:

1. Both chronic and accidental releases must be considered.
2. Wastes can be found in many different locations; e.g., truck, trench, etc.
3. There are various types of waste; e.g., fuel cycle wastes, institutional wastes, etc.
4. The wastes are in different quantities ranging from isolated small packages to large, filled trenches.
5. The physical properties of the wastes such as solubility, flammability, volatility, etc., vary.

The large number of variables make it more convenient to structure the event trees in the form of matrices where "success" or occurrence of the event is identified as (+) and the "failure" or absence of the event is identified as (-). The equivalence between the Rasmussen style event tree and the event sequence matrix is illustrated in Figure 5-8.

The variables considered in the analysis of event sequences leading to the derivation of release scenarios are illustrated in Figure 5-9. The analysis is performed for each LLW activity phase, e.g., vehicle arrival, trench backfill, post-burial, limited site use, etc. Development of event matrices start with the identification of initiating events. These initiating events are then considered for each combination of packaging, physical properties, and radionuclide content (source terms) that lead to the release of radioactivity. Illogical sequences are rejected. For example, a release of radionuclides by flooding of wastes contained in a sealed steel drum would be considered inadmissible although similar flooding of wastes contained in a carton would cause the release. Groups of events with similar consequences are indicated by a dominant scenario which is representative of the group. A detailed development of event matrices for an on-site waste handling activity is provided in Volume 3, Appendix C-2 as an illustration of the application of event matrix methodology.

The consequence of each scenario is the entry of radionuclides to the release pathways, and eventual dose commitment to the site personnel or the public. The subprograms used for these dose calculations are described in


A
B
C
D
E
Basic Tree
Initiating Event
P_A
Succeeds
Fails
Succeeds
Fails
Succeeds
Fails
Succeeds
Fails
Succeeds
Fails
P_{C_2}

A	B	C	D	E
+	+	+	+	+
+	+	+	+	–
+	+	+	–	+
+	+	+	–	–
+	+	–	+	+
+	+	–	+	–
+	+	–	–	+
+	+	–	–	–
+	–	+	+	+
+	–	+	+	–
+	–	+	–	+
+	–	+	–	–
+	–	–	+	+
+	–	–	+	–
+	–	–	–	+
+	–	–	–	–

Note 1: Succeeds = +
Fails = –

Note 2: Since there are 4 independent events, total number of sequences is $(4)^2 = 16$
The table is easily structured by alternating pluses & minuses as follows:

+ & – in column "E"
(2) + & (2) – in column "D"
(4) + & (4) – in column "C"
(8) + & (8) – in column "B"
All + in column "A" (initiating event)

Figure 5-8. Equivalence of Event Trees and Event Tables.

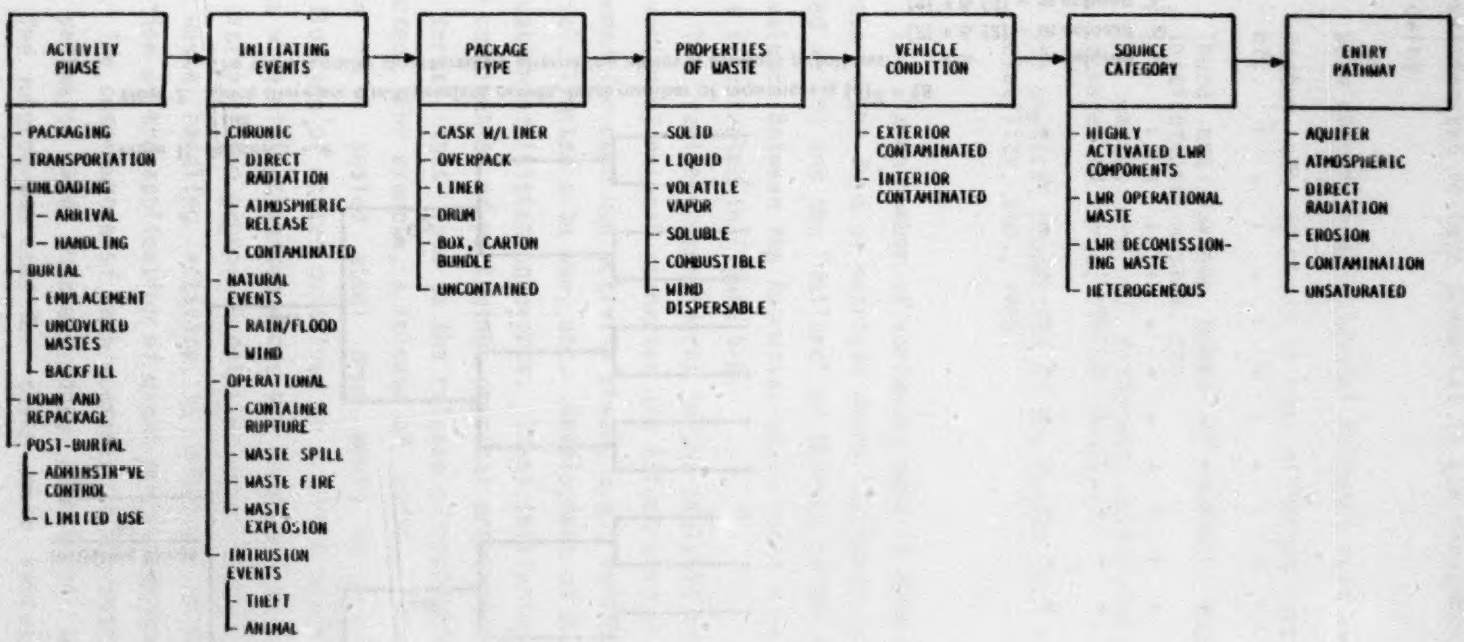

ACTIVITY PHASE
PACKAGING
TRANSPORTATION
UNLOADING
ARRIVAL
HANDLING
BURIAL
EMPLACEMENT
UNCOVERED WASTES
BACKFILL
DOWN AND REPACKAGE
POST-BURIAL
ADMINSTR'VE CONTROL
LIMITED USE
INITIATING EVENTS
CHRONIC
DIRECT RADIATION
ATMOSPHERIC RELEASE
CONTAMINATED
NATURAL EVENTS
RAIN/FLOOD
WIND
OPERATIONAL
CONTAINER RUPTURE
WASTE SPILL
WASTE FIRE
WASTE EXPLOSION
INTRUSION EVENTS
THEFT
ANIMAL
PACKAGE TYPE
CASK W/LINER
OVERPACK
LINER
DRUM
BOX, CARTON BUNDLE
UNCONTAINED
PROPERTIES OF WASTE
SOLID
LIQUID
VOLATILE VAPOR
SOLUBLE
COMBUSTIBLE
WIND DISPERSABLE
VEHICLE CONDITION
EXTERIOR CONTAMINATED
INTERIOR CONTAMINATED
SOURCE CATEGORY
HIGHLY ACTIVATED LWR COMPONENTS
LWR OPERATIONAL WASTE
LWR DECOMISSIONING WASTE
HETEROGENEOUS
ENTRY PATHWAY
AQUIFER
ATMOSPHERIC
DIRECT RADIATION
EROSION
CONTAMINATION
UNSATURATED

Figure 5-9. Variables Included in LLW Release Scenarios

Section 6. The pathways which the radionuclides follow after being released from the source to migrate to the receiver are sequentially identified after each release scenario by the sequence of numbers which identify the sequence of subprograms used in the calculations. (See tables of release scenarios in Volume 3, Appendix C. For example, in the case of fire in the waste in the overpack on the truck which is subsequently extinguished with water; some of the radionuclides are released directly to the atmosphere with the smoke and steam and some soak into the ground with the water. In the first case, the subprogram used in the calculation of the inhalation dose is ATMOS and is identified as a sequence with only the entry (1). In the second case, the radionuclides enter the unsaturated layer of the soil and can be transported to the population via the aquifer or blown into the atmophere by erosion. The appropriate sequences in which calculations will be made is by the use of subprograms UNSAT and AQUIFR (i.e., (9) and (1)) and UNSAT, EROSIO, and ATMOS (i.e., (9), (5), and (2)).

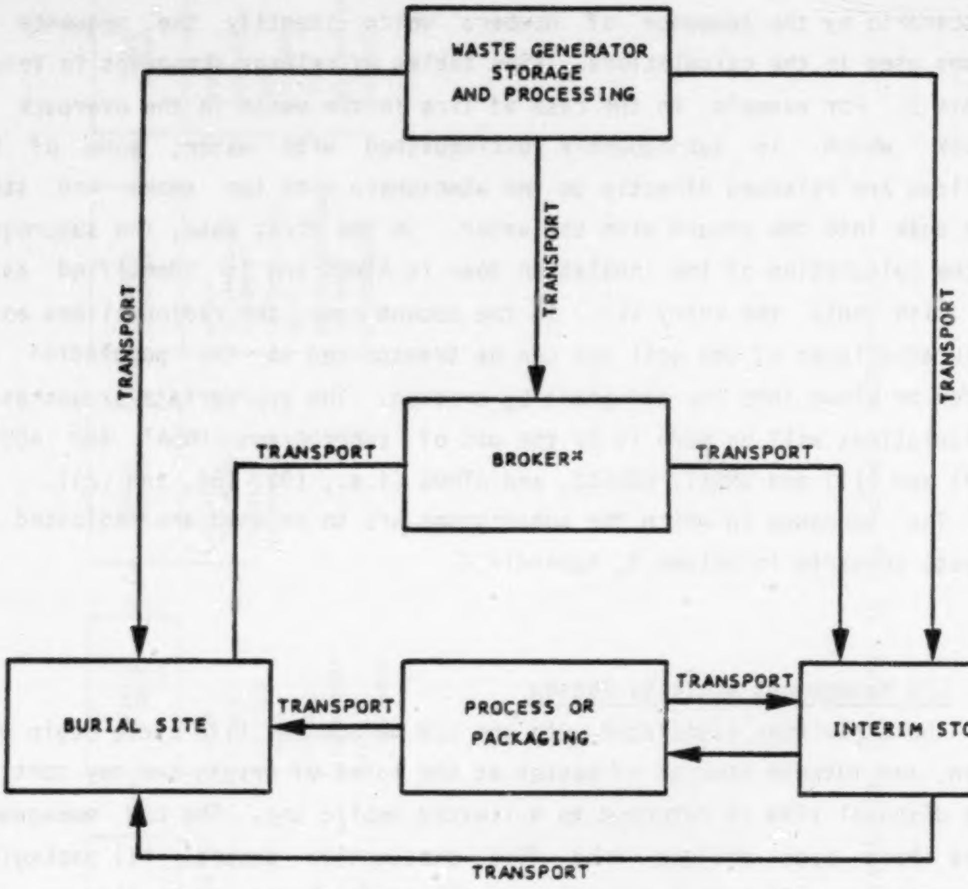
The sequence in which the subprograms are to be used are indicated for each release scenario in Volume 3, Appendix C.

5.2.2 LLW Management Activity Phases

The activities associated with the LLW management life cycle begin with generation and interim storage of wastes at the point of origin and may continue until the disposal site is returned to a limited public use. The LLW management activities have been divided into five distinctive phases: (1) packaging, (2) transportation, (3) burial operations, (4) administered post closure, and (5) limited public use. In this preliminary report only the events associated with activities which begin with the waste arrival at the burial site were considered. For completeness, however, all activity phases are discussed.

5.2.2.1 Packaging and Transportation

Packaging and transportation interactions are shown in the logic diagram of Figure 5-10. The accidental and chronic releases can occur at: (1) the sites where low-level wastes originate, (2) during LLW transport to waste broker, interim storage, process or packaging facility or to the burial site, (3) at the broker's location, (4) during interim storage, and (5) in the processing and packaging facility.


WASTE GENERATOR
STORAGE
AND PROCESSING
TRANSPORT
TRANSPORT
TRANSPORT
TRANSPORT
BROKER*
TRANSPORT
BURIAL SITE
TRANSPORT
PROCESS OR
PACKAGING
TRANSPORT
INTERIM STORAGE
TRANSPORT

* BROKER COLLECTS FROM MANY GENERATORS

Figure 5-10. Low-Level Waste Burial Operations.

In many cases, brokers collect waste from a number of sources. Broker activities can include additional processing, immediate shipment to a burial ground, or storage with subsequent shipment. Because of the nature of collection from several sources, there is some interim storage of at least a short duration.

5.2.2.2 Unloading and Burial

The typical sequence of operations at the burial site is illustrated in Figure 5-11 and includes: (1) arrival and inspection of the shipment, (2) transit to the unloading station in or near the trench, (3) emplacement in the trench, (4) covering of the trench with backfill, (5) surveillance of backfilled trenches, and (6) decontamination procedures.

Releases of radioactivity may also occur during activities associated with decontamination of equipment or site areas; during repackaging of leaking or damaged containers; or during the period when the wastes remain uncovered in the trench prior to burial.

Typical procedures used during on-site burial operations are discussed below for the purposes of illustration.

Shipment Arrival and Inspection Phase

Typically, when the truck carrying wastes arrives at the site, it is parked in a specially designated receiving area and inspected to determine the following:

1. That radiation levels for the waste packages are known and are within the specifications set by the site for the particular type of waste.
2. There are no leakers that would contaminate the site (between the receiving station and the trench).
3. The vehicle is not externally contaminated.
4. The radiation levels at the vehicle perimeter are within the site specifications.
5. That it is known what kinds and the mix of packages are in the vehicle. These could be casks, drums, boxes, cartons or in some cases, the waste may be loose in the vehicle.

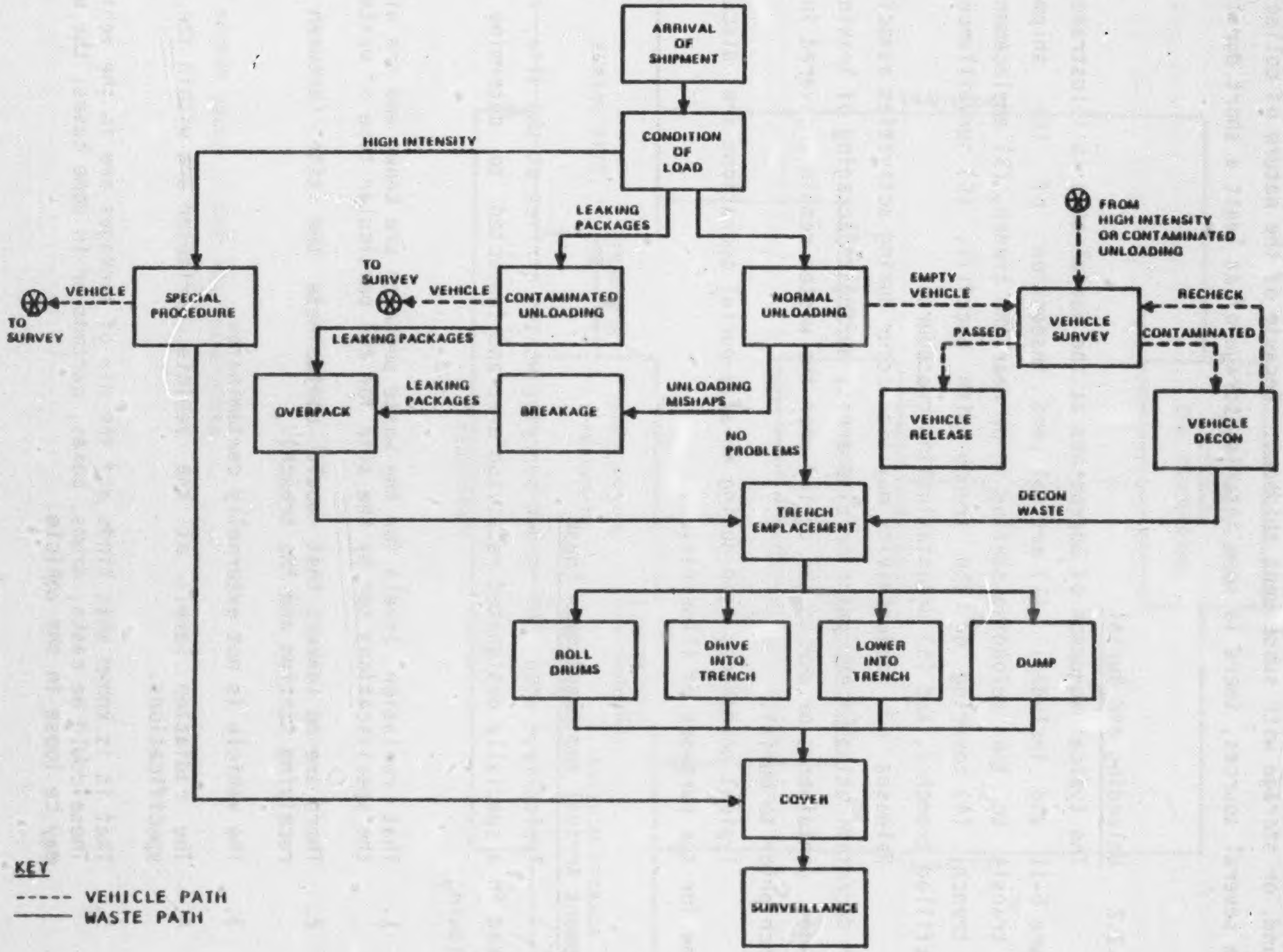

ARRIVAL OF SHIPMENT
CONDITION OF LOAD
HIGH INTENSITY
LEAKING PACKAGES
SPECIAL PROCEDURE
VEHICLE
TO SURVEY
CONTAMINATED UNLOADING
VEHICLE
TO SURVEY
LEAKING PACKAGES
NORMAL UNLOADING
EMPTY VEHICLE
FROM HIGH INTENSITY OR CONTAMINATED UNLOADING
VEHICLE SURVEY
RECHECK
CONTAMINATED
PASSED
VEHICLE RELEASE
VEHICLE DECON
DECON WASTE
OVERPACK
LEAKING PACKAGES
BREAKAGE
UNLOADING MISHAPS
NO PROBLEMS
TRENCH EMPLACEMENT
ROLL DRUMS
DRIVE INTO TRENCH
LOWER INTO TRENCH
DUMP
COVER
SURVEILLANCE
KEY
----- VEHICLE PATH
—— WASTE PATH

Figure 5-11. Low-Level Waste Burial Site Operations.

Upon successful completion of receiving inspection, the truck is allowed to enter the burial site and discharge its cargo.

Transit to the Unloading Station In or Near the Burial Trench

The first operation is to drive the vehicle to the unloading station in or near the trench. This can be done in several ways:

1. Drive the vehicle to the end of the trench in which waste is actively being placed.
2. Drive the vehicle into the trench by using a ramp at the end of the trench.
3. Drive the vehicle to the unloading point along one of the longitudinal sides of the trench.

Waste Emplacement in the Trench

When the vehicle is in any of the unloading positions, several methods can be used to unload the vehicle. Combinations of the methods can also be used.

1. For dump trucks - elevate the dump truck body and let the waste slide off into the trench.
2. Manually unload the vehicle letting the waste fall or roll into position in the trench.
3. Use a fork truck or payloader to lift waste or waste packages from the vehicle and place or dump the waste into the trench.
4. Use a crane and slings to lift waste packages from the vehicle into the trench.
5. Using rectangular waste packages, a wall is built across the trench at some distance from the covered face. The space behind the wall is filled with a mixture of irregular containers covered with soil.

For shielded casks, the following operations are necessary:

1. For casks, loosen or remove cask hold down bolts or devices to release the cask from the vehicle.
2. Use a crane and lifting devices to lower a shielded cask to a specially prepared and shielded unloading area in or near the trench.

3. Remove cover bolts or cover hold down devices from the cask lid manually or by using remotely operated tools.

4. Lift the cask lid from the cask using a crane and handling slings or tools.

5. Lift the interior canister from the cask using the crane and remotely operated grapples.

5. Carry the canister to the desired point in the trench using the crane.

7. Put the canister down in the desired burial position and disengage the grapples.

8. Return the crane to the cask unloading station.

9. Lift the cover back onto the cask.

10. Reinstall cover bolts or cover hold down devices.

11. Lift the cask from cask unloading area and place into vehicle using the crane.

12. Install the cask hold down bolts or devices to secure the cask to the vehicle.

13. Inspect the cask for external contamination.

After a vehicle is unloaded, it is driven to the discharge inspection station for clearance to leave the site.

After placement of wastes in the trench they remain uncovered for a length of time which varies depending on the radiation level surrounding the packages and the procedures followed at the burial site.

A. For the trenches containing low radiation level packages, the following procedures might be followed:

    1. Sections of partly filled trench, several meters in length are uncovered for a duration of several days or weeks.

    2. Alternatively, all wastes are covered at the end of each week.

    3. Alternatively, wastes in the trench are covered when site monitors indicate excessive radioactivity.

    4. Site personnel do not come in direct contact with uncovered wastes.

    5. Site personnel wear protective clothing and air breathing apparatus or work in protective cabs when operating equipment in the vicinity of trenches or when unloading waste shipments.

B. For the trenches containing high radiation level canisters (these are buried in narrow trenches which are about 1 meter wide), the following procedures might be followed:

   1. Containers are covered by soil immediately after placement in the trench.

   2. Personnel procedures described in A.4 and A.5 above apply.

Covering of the Trench with Backfill

Bulldozers or earthmovers are used to cover the exposed wastes with the backfill. The compaction is accomplished by riding heavy machines over the backfill.

Surveillance of Backfilled Trenches

The trenches are monitored during and ofter operations for levels of radiation exceeding standards set forth in operating licenses. Failure to bury high intensity materials (like reactor poison curtains) deep enough or excessive exposure of other materials could result in chronic high levels in trench vicinity. Prior to covering a trench monitoring is used to protect workers from high exposure from uncovered waste. Standard monitoring equipment common to the industry is used. The instruments are maintained and checked by site health physics personnel.

Decontamination Procedures

A variety of items may require decontamination because of the presence of radioactive materials on the exterior surfaces of vehicles or equipment either on site or when being released to offsite. Contamination may be present in interior surfaces of vehicles that are being released for hauling general cargo. Radioactivity may also be present at points on the site external to the trench that may require decontamination. A number of procedures may be followed to perform decontamination of an area or object.

1. The vehicles or equipment can be decontaminated at the point where a survey for radioactivity indicates a problem, or the vehicle can be driven to a decontamination station. The decontamination station may be in the burial trench or may be a special location on the site surface.

2. The site can be decontaminated by scraping the affected area and removing the soil either by hand or using earth handling equipment; or the surface of the affected area can be coated by additional earth or a permanent coating such as asphalt or concrete.

3. The contaminated cloths can be disposed of by placing them in plastic bags and burying the bags in the waste trench. The condensate from steam cleaners can be collected in sumps or drains. The water can be filtered. If the filtered water is considered clean, it can be discarded without care. If the water is considered contaminated, then the contaminated solution can be solidified and buried in the waste trench.

4. Waste that does not meet the site specifications for control of the spread of contamination (leaking packages or packages with external contamination) or limit the radiation levels at the package surface or at the vehicle boundary may be repackaged at the site before burial.

5.2.2.3 Post-Closure - Administrative Period

During this period, the site is still under administrative control. Release pathways during the post-closure period depend mainly on the as-buried condition of the waste, the geologic/hydrologic environment, and the nature of post-closure administration.

5.2.2.4 Unrestricted Use Period

During this period, there is no site management activity. The land is released for public use which would be tailored for minimum disturbance of the burial areas (i.e., no significant excavation or drilling). An example of such use would be a park or golf course. Radionuclide release pathways will depend strongly on the as-buried condition of the waste and site geology/hydrology. Because of lack of administrative control, a fairly extensive list of event-type and chronic pathways is possible during this period. Examples of such pathways are human intrusion, animal intrusion, crop or plant absorption,, and natural disruptions (flood, seismic activity, etc.).

5.2.3 Initiating Events

The initiating events that lead to the release scenarios identified in Volume 3, Appendix C fall into the following categories: (1) chronic releases, (2) natural events, (3) operational events, (4) intrusion events. The magnitude of the dose associated with these events will depend on the amount and composition of the released material (inventory and release fraction) and on various attenuating factors including use of remotely operated handling equipment, wearing of protective clothing or breathing apparatus, administrative control of entry etc. These variable factors will have been specified as an additional variable input to each release scenario.

5.2.3.1 Chronic Releases

The events of concern are as follows:

1. Chronic Release of Direct Radiation to Site Workers - This may originate from activities associated with handling of wastes prior and during the burial or from inadequate shielding by trench coverage.

2. Chronic Release of Radionuclides to Atmosphere - These releases and their subsequent inhalation by site workers or the public may be caused by the outgassing of volatile substances, continuously or intermittently, from buried wastes or from on-site wastes handling.

3. Chronic Site Contamination - If the burial site is allowed to be contaminated it may cause a chronic contamination of site workers and eventual penetration to the public after the removal of administrative controls.

5.2.3.2 Natural Events

1. Rain/Flood - These events are of greatest significance to the post burial phases when containers are assumed to be ineffective. The magnitude of release will depend on the amount of water seepage through the trenches and the solubility of the radionuclides contained in wastes. A flood might be considered to be the limiting case of a heavy rain. The waterproofing qualities of packaging and the solubility of wastes will have to be specified in evaluating flooding accidents in pre-burial phases.

2. Wind - The events that might lead to the dispersal of radionuclide by strong winds are most likely to occur during the pre-burial phase when loosely bound packages of a light paper or powdery substance are in the uncovered trench awaiting burial.

5.2.3.3 Operational Events

1. Container Rupture - These events are of interest only during the pre-burial phases, e.g., transportation or on-site handling of the waste packages. After the burial, the containers are assumed to be disintegrated and do not provide containment of radionuclides. Whether the radionuclides are released in the event of container rupture depends on the size of the split and the properties of enclosed wastes. Obviously, volatile substance will escape most readily while solid waste imbedded in concrete or asphalt may not cause any significant contamination even in the event of container disintegration.

2. Waste Spills - Similar to the container ruptures, these events apply only to pre-burial phases. They may be caused by accidental openings of the packages or by activities of the personnel.

3. Waste Fires - Similar to the previous events, the fires are pertinent only to pre-burial activities. The waste can be involved in fires that are initiated and supported by external causes, e.g., truck fires or the waste material itself may support combustion and provide the source of energy as for example, in the case of fires in an unburied trench. The amount of radionuclides released in these events depends very strongly on the assumptions relative to the fire resistance of packaging and combustibility of wastes, e.g., presence of wooden boxes, bundled papers, etc.

4. Waste Explosions - The initiation of these events can be caused by the build up of significant gas pressures inside airtight containers, or by the presence of explosive materials among waste packages. Unlike the previous events, the explosions can occur during pre-burial as well as post-burial phases. The force of the explosion will have to be specified for the analysis when evaluating a specific circumstance.

5.2.3.4 Intrusion Events

1. Theft of Usable Items - The events of concern are theft by site workers of items such as tools, instruments or items containing valuable materials from the waste consigned to burial. These stolen items may cause direct irradiation or contamination of site personnel or the public.

2. Animal Intrusion - These events describe the possibilities of small animals such as rabbits, gophers, etc., burrowing into the trenches containing wastes. They may become contaminated and become carriers to the pathways resulting in the dose to humans.

3. Human Intrusion - These events are concerned with the use of the site after its return to limited use. The activities of humans associated with the use of the land include farming, forestry, recreation, etc. In very long periods of times, e.g., on the order of 10^3 years, habitation and digging for artifacts may occur.

6. MODEL DESCRIPTION

6.1 OVERVIEW

6.1.1 Objectives

The Shallow-Land Burial (SLB) Systems Model is being developed to provide a means of evaluating licensing alternatives in terms of site and operational parameters. The objective is to provide a user-oriented code which makes efficient use of available data to perform dose assessments of various assumed scenarios. The SLB Model is designed from existing models and codes so that it is composed of previous established methodologies. The SLB Systems Model is not intended to be a risk model in the sense that all possibilities are considered and the most rigorous calculation made. The SLB Model is rather directed toward making comparisons of situations to weigh alternatives. A set of scenarios is being provided with the SLB Model. These have been developed from detailed event-tree type analysis and are considered to be a reasonably complete list of major initiating events which have been condensed from a larger list. The SLB Model is programmed so that additional scenarios can be analyzed by supplying a source term and a pathways calling sequence.

6.1.2 Assumptions

Detailed assumptions involved in the individual transport and dose submodels are discussed in the appropriate parts of Section 6. Assumptions stated here are major overall system assumptions. The SLB Systems Model is composed of a series of pathways subprograms which view the environment as a system including a seepage column with waste at the surface or at a subsurface location which communicates with a saturated aquifer which then connects with surface water bodies. In addition, the land surface communicates with the atmosphere. The key assumptions are:

- Waste in trenches is homogeneous in nuclide distribution and package type distribution.

- The seepage column is a vertical column with properties and events uniform horizontally.

- The effect of discharge to the aquifer on the soil column is coupled.

- Daughter products are not calculated from initial inventory but decay is applied to nuclides in all paths.

- The aquifer is a one-dimensional "pipe" direct to a surface body of concern.

- The effect of loss of nuclides from the soil surface is not coupled to the seepage subprogram.

- The atmospheric path is one-dimensional sector-averaged and direct to the population of concern.

- Air and water concentrations are carried through food chain and exposure paths as viewed by standard dose assessment procedures.

The analysis begins with a scenario as an initiating event and carries the source term through appropriate paths or series of paths to obtain air and water concentrations which are converted to dose commitments using standard dose assessment methods (see Section 6.8).

6.2 EXECUTIVE PROGRAM (EXEC)

The executive program integrates the transport and dose calculation subprograms. The reading of input data, writing of output data, sorting and data preparation, and calling sequence of subprograms are handled by the executive program. The executive program draws from a number of data bases:

- Dose factor and nuclide data prepared by PREDOS from the master data base.

- Weather data (input by user).

- Geologic data (input by user).

- Scenario source term (internal data base).

- Scenario calling sequence (internal data base).

- Demographic data (input by user).

- Miscellaneous options switches (input by user).
- Miscellaneous other input data.

Prior to running the executive program, all the necessary data is supplied by an input deck (for batch mode) or on a system disc file (interactive mode).

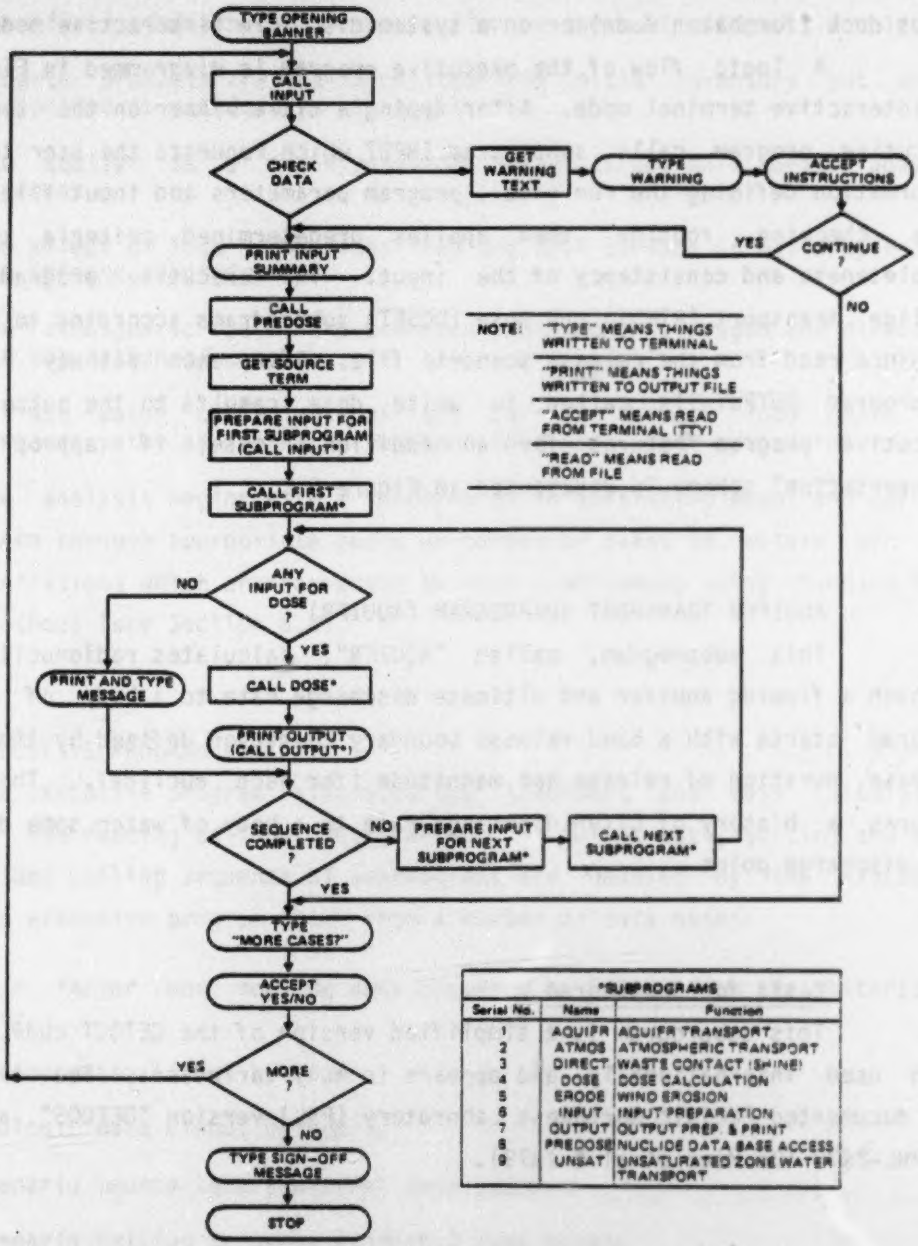
A logic flow of the executive program is diagrammed in Figure 6-1, in an interactive terminal mode. After typing a title banner on the terminal, the executive program calls subprogram INPUT which requests the user to supply key information defining the run (i.e., program parameters and input file names). A data checking routine then applies predetermined criteria to test for completeness and consistency of the input. The executive program calls the nuclide transport (ATMOS) and dose (DOSET) subprograms according to the pathways sequence read from the release scenario file. After each pathway is completed subprogram OUTPUT is called to write dose results to the output file. The executive program returns for an additional case, if appropriate. The "conversation" scheme is repesented in Figure 6-2.

6.3 AQUIFER TRANSPORT SUBPROGRAM (AQUIFR)

This subprogram, called "AQUIFR", calculates radionuclide transport through a flowing aquifer and ultimate discharge rate to a body of water. The program starts with a band release boundary condition defined by time of initial release, duration of release and magnitude (for each nuclide). The subprogram returns a history of Ci/yr discharge rate to a body of water some distance from the discharge point.

6.3.1 Basis for Subprogram

This subprogram is a simplified version of the GETOUT code. GETOUT has been used internationally and appears in many variations. The version used is the documented Pacific Northwest Laboratory (PNL) version "GETOO5" as described in PNL-2970 (De Mier et al., 1979).


TYPE OPENING BANNER
CALL INPUT
CHECK DATA
GET WARNING TEXT
TYPE WARNING
ACCEPT INSTRUCTIONS
CONTINUE ?
YES
NO
PRINT INPUT SUMMARY
CALL PREDOSE
GET SOURCE TERM
PREPARE INPUT FOR FIRST SUBPROGRAM (CALL INPUT*)
CALL FIRST SUBPROGRAM*
ANY INPUT FOR DOSE ?
NO
YES
PRINT AND TYPE MESSAGE
CALL DOSE*
PRINT OUTPUT (CALL OUTPUT*)
SEQUENCE COMPLETED ?
NO
PREPARE INPUT FOR NEXT SUBPROGRAM*
CALL NEXT SUBPROGRAM*
YES
TYPE "MORE CASES?"
ACCEPT YES/NO
MORE ?
YES
NO
TYPE SIGN-OFF MESSAGE
STOP
NOTE: "TYPE" MEANS THINGS WRITTEN TO TERMINAL
"PRINT" MEANS THINGS WRITTEN TO OUTPUT FILE
"ACCEPT" MEANS READ FROM TERMINAL (TTY)
"READ" MEANS READ FROM FILE

*SUBPROGRAMS

Serial No.	Name	Function
1	AQUIFR	AQUIFR TRANSPORT
2	ATMOS	ATMOSPHERIC TRANSPORT
3	DIRECT	WASTE CONTACT (SHINE)
4	DOSE	DOSE CALCULATION
5	ERODE	WIND EROSION
6	INPUT	INPUT PREPARATION
7	OUTPUT	OUTPUT PREP. & PRINT
8	PREDOSE	NUCLIDE DATA BASE ACCESS
9	UNSAT	UNSATURATED ZONE WATER TRANSPORT

Figure 6-1. Shallow Land Burial System Model Executive Program.

Figure 6-2. A Typical Terminal Session in the Conversational Mode. The Underlined Data is User Supplied.

```
LGO.
  WHAT SCENARIO ARE YOU RUNNING?

10

  WHAT IS THE EXPOSURE TIME? (HRS)

.5

  WHAT IS THE VOLUME OF THE BOX OR PACKAGE INVOLVED IN THIS
  SCENARIO?

1.

  WHAT IS THE VELOCITY OF THE WIND AT THE ACCIDENT? (M/SEC)

1.

  WHAT IS THE DIAMETER IN METERS OF THE DUST CLOUD RELEASED
  IN THIS SCENARIO?

10.
  SCENARIO:  10 COMPLETED

  DO YOU WISH TO RUN ANOTHER SCENARIO?
NO

  GOOD BYE FROM SHALLOW LAND

STOP

END OF EXECUTION
CPU TIME:  6.17  ELAPSED TIME:  1:27.00
```

The main differences between AQUIFR and GET005 are the deletion of input/output file manipulation, changes in method of input band description, and deletion of daughter product chain calculations. The first two changes are necessary to accomodate the role of this subprogram in the Shallow Land Burial Systems Model. Deletion of daughter products is justified by the lack of significant amounts of nuclides which present daughter product concern in the Shallow Land Burial System. Calculation of daughter product transport requires tremendous increase in program size and complexity. GET005 is four separate programs running several hundred pages, deletion of daughter product calculations reduces the size by more than 75 percent.

The key assumptions for the model are:

- One-dimensional flow and transport (conservative)
- Axial dispersion (constant dispersion coefficient)
- Equilibrium adsorption on the soil
- Constant water velocity in the aquifer
- No "discharge effect" - the aquifer is assumed infinite in length with no feed back to transport within the aquifer as a result of type of discharge. This assumption is valid for reasonable aquifer length; if dispersion length is short compared to aquifer length (Oston, 1979).

6.3.2 Discussion

The discharge point of a subsurface, partially saturated soil column (see Subsection 6.6) is assumed to be connected by a one-dimensional aquifer "pipe" to a surface body of water. The input to the aquifer is described as a band of constant magnitude beginning and ending at a specified time. The water flows at a constant rate through the aquifer to the surface body (or well). The dissolved radionuclides are in sorption equlibrium with the soil at all points and undergo decay. Trace concentrations of the dissolved nuclides are assumed so that the sorption equilibrium constants are independent of concentration. A constant axial dispersion coefficient is assumed.

In terms of a rectangular coordinate system stationary at the aquifer inlet, the migration of a nuclide is described by (Lester et al., 1975).

$$D\frac{\partial^2 N}{\partial Z^2} - V\frac{\partial N}{\partial Z} - K\frac{\partial N}{\partial t} - K\lambda N = 0 \qquad (1)$$

where

D = disperison coefficient (cm^2/yr)

N = discharge rate (Ci/yr)

V = water velocity (cm/yr)

Z = aquifer length (cm)

K = sorption equilibrium constant (no units)

λ = nuclide decay constant (yr^{-1})

t = time (yr)

The sorption equilibrium constant is related to the distribution coefficient (K_d) by

$$K = 1 + \frac{K_d \rho}{\varepsilon} \qquad (2)$$

where

K_d = distribution coefficient

ρ = solid bulk density

ε = void fraction of solid

As defined, the equilibrium constant (K) relates relative nuclide and water velocity (without dispersion) as:

$$K = \frac{\text{water velocity}}{\text{nuclide velocity}} \tag{3}$$

For a band release of duration T, the inlet boundary condition is given by:

$$N = \frac{N^{0}}{T} \exp(-\lambda t) \quad \text{at} \begin{cases} 0 \ t \ T \\ Z = 0 \end{cases} \tag{4}$$

where N^{0} is the total amount of radionuclide discharged over time period T. Note that decay at the input source is accounted for in the inlet condition (Equation 4). The other boundary conditions are:

$$\begin{aligned} N &= 0 \quad &&\text{at} \quad t=0 \quad &&0 \underline{<} Z < \infty \\ N &= \text{finite} \quad &&\text{at} \quad t>0 \quad &&Z=\infty \end{aligned} \tag{5}$$

This equation has been solved analytically by Laplace transform techniques (Lester, et al., 1975). The solution for curies discharged at the end of the aquifer is:

$$\begin{aligned} N = \frac{N^{0}}{2T} \Bigg\{ & \exp(-R\theta) \left[\operatorname{erfc}\left(\sqrt{\frac{KP}{4\theta}} - \sqrt{\frac{P\theta}{4K}} \right) \right. \\ & \left. + \exp(P) \operatorname{erfc}\left(\sqrt{\frac{KP}{4\theta}} + \sqrt{\frac{P\theta}{4K}} \right) \right] \\ & - \exp\left[-R(\theta-\theta_T) \right] \left[\operatorname{erfc}\left(\sqrt{\frac{KP}{4(\theta-\theta_T)}} - \sqrt{\frac{P(\theta-\theta_T)}{4K}} \right) \right. \\ & \left. + \exp(P) \operatorname{erfc}\left(\sqrt{\frac{KP}{4(\theta-\theta_T)}} + \sqrt{\frac{P(\theta-\theta_T)}{4K}} \right) \right] \Bigg\} \end{aligned}$$

where $R = \frac{\lambda L}{V}$ = dimensionless decay number

$\theta = \frac{tV}{L}$ = dimensionless time

$\theta_T = \frac{\tau V}{D}$ = dimensionless release time

$P = \frac{TV}{L}$ = Peclet number

L = aquifer length

T = time of release duration

λ = radioactive decay constant

While the calculation of discharge rate for any given time using Equation (6) is a relatively simple operation, there are several special features which support the calculation. First, for most problems of interest one encounters severe accuracy problems which can result in total loss of the results in machine error. This is because error function complement (erfc) values for very large arguments are often required. The result is often a very small number which can cause machine underflow. Most machines then assign a zero value thus eliminating the time results. Usually the very small number (say, 10^{-50}) is multiplied by an exponential which is very large (say 10^{48}) resulting in a reasonable answer (10^{-2}). This problem is handled in a special subroutine "FERRNT" which is taken from the literature and incorporated into "GET005" (and therefore "AQUIFR"). FERRNT calculates accurate (exp)x(erfc) products in asymtotic regions using sealing of arguments prior to execution. Some machine dependent factors involving binary word length, and machine overflow are used by FERRNT. Second, there is a general accuracy problem which is handled by running the entire code in double precision; this is a necessity. Third, the code carries most numbers as exponents until the final result is obtained; this helps avoid machine numerical overflow. Fourth, AQUIFR incorporates a peak conditioning routine so that well proportioned time scans of nuclide discharge peaks are produced. AQUIFR was tested against an unmodified GET005 test run obtained from PNL.

6.3.3 Interfaces

AQUIFR is called by the executive program (BURYIT) in situations where nuclides have been discharged to the aquifer. The following input is required:

- Number of nuclides and their labels.
- Sorption equilibrium coefficients for each nuclide.
- Aquifer water velocity.
- Dispersion coefficient.
- Length of aquifer.
- Input band information, inventory discharged, band input period, and width of band.

In the Shallow-Land Burial Systems Model, the band width and inventory are calculated by UNSAT, the unsaturated zone transport code. The aquifer lies at the bottom of the soil column. UNSAT calculates population behavior and determines discharge amounts and time by nuclide over a prescribed time for a given nuclide inventory.

Subroutine AQUIFR returns discharge rates to a body of water as Ci/yr over an appropriate time period (as determined by the peak conditioning routine) for each nuclide. The discharge rates are converted through the executive program and the DOSE subprogram into dose from ingestion and other water related pathways.

6.4 ATMOSPHERIC TRANSPORT SUBPROGRAM (ATMOS)

6.4.1 Basis for Subprogram

The function of subprogram ATMOS and its subroutines SIGMAZ and DINT is to calculate the dispersion of radionuclides released to the atmosphere. Basic inputs to the subprogram are quantity of radionuclides released and weather data; the basic output is the spatial-dependent air and ground concentrations of the various radionuclides.

The basic approach to the atmospheric transport subprogram is the Gaussian plume model as described in "Slade, D. H. (1968)," and as used in a number of computer programs such as XOQDOQ (J. R. Sagendorf and J. T.Goll 1976).

In the Gaussian plume model, advantage is taken of the fact that natural diffusion in the atmosphere leads to a known (Gaussian) distribution of pollutants in the atmosphere. This Gaussian plume model is combined with available formulations for plume rise, deposition and cloud depletion to complete the atmospheric transport model.

6.4.2 Discussion

Gaussian Plume Model Chi (χ) over Q

The Gaussian plume model gives the atmospheric density of a contaminant, χ , as a function of location downwind from a source of strength, Q, and as a function of other parameters such a release height, crossrange distance from plume centerline, and weather conditions. There are several Gaussian plume formulations for different release conditions and for different use applications. One formulation gives the time-dependent χ'/Q following an instanteous "puff" release; another gives the time steady-state χ/Q for a continuous steady-state release. Some formulations give the total x,y,z location dependence of χ/Q, while other formulations give the plume centerline (maximum) or the sector-averaged χ/Q.

One χ/Q desired is the time-integrated value as seen by a stationary observer who experiences the cumulated effect of the passing debris cloud from a puff release. The time-dependent formula for a puff release is:

$$\chi'(x,y,z,h,t) = \frac{Q_o F_d}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp\left\{ -\left[\frac{(x-ut)^2}{2\sigma_x^2}\right] \right\} \exp\left\{ -\frac{y^2}{2\sigma y^2} \right\}$$

$$x \left\{ \exp\left[-\frac{(z-h)^2}{2\sigma_z^2} \right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2} \right] \right\} \qquad (1)$$

where (using mks units)

χ' is cloud concentration, Ci/m^3;

Q_o is initial release quantity, curies;

F_d is a depletion factor, dimensionless;

x is downwind coordinate, meters;

y is crosswind coordinate, meters;

z is elevation coordinate, meters;

h is release height, meters;
u is wind velocity, meters/second;
t is time after puff release, seconds;
$\sigma_x, \sigma_y, \sigma_z$ are x-dependent plume width standard deviations for the downwind, crosswind and vertical directions, respectively (meters).

Expressions for σ_y and σ_z from Sagendorf and Goll (1976) are given in Table 5-1.

Integration of Equation 1 over the time of the cloud passage yields

$$\chi(x,y,z,h) = \frac{Q_o F_d}{2\pi\sigma_y\sigma_z u} \exp\left\{-\frac{y^2}{2\sigma_y^2}\right\}\left\{\exp -\left[\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right]\right\} \tag{2}$$

where is the time-integrated cloud concentration at location (x,y,z) with units of Ci-sec/m^3.

For cloud concentrations at the ground level (z=0), Equation 2 reduces to

$$\chi(x,y,0,h) = \frac{Q_o F_d}{\pi\sigma_y\sigma_z u} \exp\left\{-\left[\frac{y^2}{2\sigma_y^2} + \frac{h^2}{2\sigma_z^2}\right]\right\} \tag{3}$$

The sector averaged χ/Q is obtained by integrating (3) over y and dividing by the sector width $2\pi x/n$ at downwind distance x. For n=16 sectors, this is

$$\overline{\chi}(x,0,h) = \frac{2.0318 Q_o F_d}{\sigma_z u x} \exp\left[-\frac{h^2}{2\sigma_z^2}\right] \tag{4}$$

The time integrated formulas (Equations 2, 3 and 4) are identical with the Gaussian plume expressions for steady-state cloud concentrations for a steady-state release. Except for the inclusion of the depletion factor, F_d, Equations 2 and 3 are identical to Equations 3.115 and 3.116 in Slade 1968. When applied to steady-state releases, however, Q_o in Equations 2, 3 and 4 is the release rate (e.g., Ci/second) and χ is the cloud concentration in Ci/m^3.

Equations 3 and 4 (with y=0 in the former) are the Gaussian plume expressions used in this study. For a puff release, e.g., with the release term Q_o expressed in curies, the resulting value of is the time-integrated

Table 6-1. Plume Width Standard Deviations (from XOQDOQ)

Crossrange standard deviation:

$$\sigma_y = ax^b\text{, meters}$$

$$a = \begin{cases} 0.3658 & \text{Stability Class A} \\ 0.2751 & \text{B} \\ 0.2089 & \text{C} \\ 0.1471 & \text{D} \\ 0.1046 & \text{E} \\ 0.0722 & \text{F} \\ 0.0498 & \text{G} \end{cases}$$

$b = 0.9031$

$x =$ down wind distance, meters

Vertical standard deviation:

$$\sigma_z = ax^b+c\text{, meters}$$

	A	B	C	D	E	F	for
a	0.192	0.156	0.116	0.079	0.063	0.053	$x < 100$ meters
	0.00066	0.0382	0.113	0.222	0.211	0.986	$100 \leq x < 1000$
	0.00024	0.055	0.113	1.26	6.73	18.05	$1000 \leq x$
b	0.936	0.922	0.905	0.881	0.871	0.814	$x < 100$
	1.941	1.149	0.911	0.725	0.678	0.74	$100 \leq x < 1000$
	2.094	1.098	0.911	0.516	0.305	0.18	$1000 \leq x$
c	0	0	0	0	0	0	$x < 100$
	9.27	3.3	0	-1.7	-1.3	-0.35	$100 \leq x < 1000$
	-9.6	2	0	-13	-34	-48	$1000 \leq x$

For stability class G: $\sigma_G = \sigma_F^2/\sigma_E$

air-ground interface concentration in Ci-sec/m^3. When χ is multipled by a breathing rate in m^3/sec, the result is the number of curies inhaled. When multiplied by cloud shine dose factor in Rem/hour per Ci/m^3 and a conversion factor of 1 hour/3600 sec, the result is cloud shine dose in Rem. For a steady-state release e.g., with the release term Q_0 expressed in Ci/sec, the resulting value of is the steady-state air-ground interface concentration in Ci/m^3. When χ is multiplied by a breathing rate in m^3/sec and an exposure time in seconds, the result is curies inhaled. When χ is multiplied by the cloud shine dose factor and an exposure time, the result is cloud shine dose in Rem.

Dry-Deposition and Depletion

The method for calculating the depletion factor, F_d, by ground deposition was not described in the above discussion. Also, the deposition of plume material onto the ground is of interest because it is the deposited material from this deposition which results in ground exposure. Deposition is of two types, dry or wet, depending on the absence or presence of precipitation. The method for calculating dry deposition and depletion, discussed below, is the method described in Section 5-3.2 of Slade 1968.

The deposition of plume material onto the ground is related to the concentration in the air at ground level by an effective velocity, v_d.

$$D(x,y) = v_d \, \chi(x,y,0) \tag{5}$$

For a puff release, the units of χ were Ci-sec/m^3; thus, with velocity units of meters per second, the units of D are Ci/m^2. For a steady-state release, D is the deposition rate in curies/m^2 per second.

The deposition velocity, v_d, is discussed in Section 5-3.2.3 of Slade 1968. The deposition velocity is about 0.002-0.01 m/sec for small particles and about the gravitation settling velocity for larger particles. A value of zero is usually used for noble gases Kr, Xe, and Rn.

The dry depletion factor, F_d, results from plume depletion by deposition of plume material onto the ground. The quantity of plume material, Q_x, passing a point at distance x from the source is reduced with distance from the source as follows:

$$\frac{dQ_x}{dx} = -\int_{-\infty}^{\infty} D(x,y)\,dy$$

$$= -\sqrt{2/\pi}\ \frac{v_d Q_x}{u\sigma_z}\ \exp\left(-\frac{h^2}{2\sigma_z^2}\right)$$

The total depletion from the source to point x is determined as follows:

$$\int_0^x \frac{dQ_x}{Q_x} = -\sqrt{2/\pi}\ \frac{v_d}{u} \int_0^x \frac{dx}{\sigma_z\ \exp(h^2/2\sigma_z^2)}$$

or

$$F_d = \frac{Q_x}{Q_o} = \exp\left\{-\sqrt{2/\pi}\ \frac{v_d}{u} \int_0^x \frac{dx}{\sigma_z \exp(h^2/2\sigma_z^2)}\right\} \qquad (6)$$

Equation 6 is equivalent to Equation 5.48 in Slade 1968.

Unfortunately, the integral in Equation 6 does not have an analytic solution for practical expressions of $\sigma_z(x)$, and accurate numerical solution is time consuming. The integral has therefore been evaluated numerically for an array of values of x, h and stability category. Values of this depletion integral are derived by double interpolation (on x and h) of the stored values.

Wet Deposition and Depletion

The deposition of plume material onto the ground during periods of precipitation is related to the total quantity of material in the plume by a washout coefficient Λ (Equation 5.63 in Slade 1968).

$$D(x,y) = \Lambda \int_0^{\infty} \chi(x,y,z)\,dz \qquad (7)$$

Typical units of Λ are $\sec^{-1}$. Integration of the above expression using $\chi(x,y,z)$ from Equation 2 yields

$$D(x,y) = \frac{\Lambda Q_o}{\sqrt{2\pi}\,u\sigma_y} \exp\left(-\frac{y^2}{2\sigma y^2}\right) \qquad (8)$$

The sector averaged D(x) is, for a 16-sector polar grid,

$$\overline{D}(x) = \frac{2.5465 \Lambda Q_o}{ux} \qquad (9)$$

The cloud depletion factor for wet deposition is derived in a manner similar to the dry depletion factor,

$$\frac{\partial Q_x}{\partial x} = - \int_{-\infty}^{\infty} D(x,y)dy$$

$$= - \frac{Q_x \Lambda}{u} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/(2\sigma y^2)} \, d(\frac{y}{\sigma y})$$

$$= - \frac{Q_x \Lambda}{u}$$

Thus

$$\frac{\partial Q_x}{Q_x} = - \frac{\Lambda}{u} \partial x$$

$$\int_0^x \frac{\partial Q_x}{Q_x} = \int_0^x - \frac{\Lambda}{u} \partial x$$

$$F_d = \frac{Q_x}{Q_0} = \exp \left(- \frac{\Lambda x}{u}\right) \qquad (10)$$

The washout factor Λ is discussed in Slade 1968, Section 5-4.5 through 5-4.9. It is clearly a function of rainfall rate and plume particle characteristics. For a reasonable particle size (e.g., density 5 g/cm^3 and diameter of 3 microns), Λ can be calculated from the following:

$$\Lambda = 0.00016 \, (RR)^{.85} \sec^{-1} \qquad (11)$$

where RR is the rainfall rate in millimeters per hour. For an annual rainfall of RF meters per year and an effective fraction of time that it is raining, FR, the washout coefficient, based on the average rainfall rate, is

$$\Lambda = 2.35\text{x}10^{-5} (RF/FR)^{.85} \qquad (12)$$

6.4.3 Applications

The Gaussian plume model just described can be applied for either puff release conditions or for long-term releases. For puff releases, the weather is usually regarded as fixed, i.e., having a specific wind direction, stability class and velocity. It will either be raining or will not be raining. For long-term releases, a mixture of weather conditions will apply. The corresponding disperson is usally called "annual average."

Both conditions may be solved using the same formulas. The air concentration is given by

$$AC(I,J,K) = Q_0(I)*(1-FR)* \sum_{L,M} F_{dry}(I,J,L,M)*\frac{\chi}{Q_0}(J,L,M)*F(K,L,M)$$

$$+ Q_0(I)*FR* \sum_{L,M} F_{wet}(K,J,L)*\frac{\chi}{Q_0}(J,L,M)*F(K,L,M) \qquad (13)$$

and the ground concentration is given by

$$GC(I,J,K) = Q_0(I)*(1-FR)*V_d(I)* \sum_{L,M} F_{dry}(I,J,L,M)*\frac{\chi}{Q_0}(J,L,M)*F(K,L,M)$$

$$+ \frac{2.5465*Q_0(I)*FR*\Lambda(I)}{X(J)} \sum_{L,M} \frac{F(K,L,M)}{U(L)} \qquad (14)$$

In the above, I, J, K, L, M are indices on isotope, distance, direction, wind speed, and stability category, respectively; FR is the fraction of the time that it rains; F_{wet} and F_{dry} are the wet and dry depletion factors (Equations 10 and 6, respectively); and F(K,L,M) is the weather frequency array giving the fraction of the time that the wind blows in direction K with speed L and stability category M.

While Equations 13 and 14 are structured for a long-term release, they can be used for a puff release by simply summing over one term, i.e., F(K,L,M) of unity for the K, L, M of interest and zero elsewhere, and with FR having a value of zero (if not raining) or 1.0 (if raining at the time of the puff release). For either puff or long-term releases, the total release in curies is entered as Q_0 (not release rate in curies/second). For a chronic, long-term release, Q_0 is the total release over a time period of interest. The corresponding air concentration result, AC, is the time integrated air concentration for that time period, in units of curies-sec/m^3. The corresponding "ground concentration," GC, is the cumulated ground deposition in curies/m^2 for that time period instead of a true ground concentration.

This procedure has been programmed in the ATMOS module, c.f., flow diagram in Figure 6-3. The plume rise, χ/Q, wet and dry depletion, and deposition are calculated in subprogram ATMOS. The subroutines SIGMAZ and DINT of ATMOS evaluate σ_z and the dry depletion integral (the integral in Equation 6), respectively. Two simplifications have been made in ATMOS. First, air transport in only one direction is considered. Thus, the wind always blows from the hypothetical source to the hypothetical exposed population. Second, all nuclides, with exceptions, must have the same deposition velocity. The exceptions are nuclides, like noble gases, which have a zero deposition velocity. Also, nuclides with a zero deposition velocity are assumed to have a zero washout coefficient, while nuclides with a non-zero deposition velocity are assumed to have the washout coefficient given by Equation 12.

6.4.4 Interfaces

Subprogram ATMOS requires the following input data:

NI - number of isotopes, maximum 54

CI - array giving source for each isotope, curies

VD - deposition velocity for each isotope, meters/second

FR - fraction of time that it rains

RF - annual rainfall, meters

NU - number of wind speed categories, maximum 10

NS - number of stability cateogies, maximum 7

KS - stability category number

Enter KS=0 for all NS categories

Enter 1<KS<7 for category KS only

U - array of wind speeds, meters/second

F - double dimensioned array of wind frequencies, dimensionless, sum normalized to 1.0

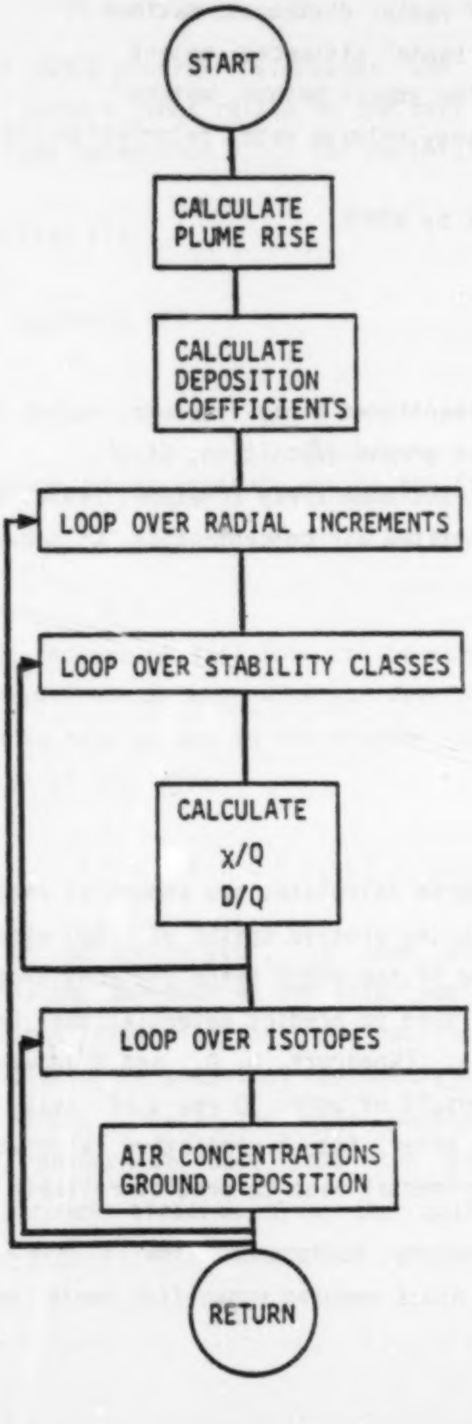

START
CALCULATE PLUME RISE
CALCULATE DEPOSITION COEFFICIENTS
LOOP OVER RADIAL INCREMENTS
LOOP OVER STABILITY CLASSES
CALCULATE χ/Q D/Q
LOOP OVER ISOTOPES
AIR CONCENTRATIONS GROUND DEPOSITION
RETURN

Figure 6-3. Subprogram ATMOS Flow Diagram

NR - number of radial distances, maximum 20
RM - array of radial distances, meters
SH - release (or stack) height, meters
SQ - stack energy release rate, calories/second

The following are output by ATMOS

GC - double dimensioned array (isotope, radial distance) of cumulative ground deposition, Ci/m^2.
AC - double dimensioned array (isotope, radial distance) of time integrated air concentration, Ci sec-/m^3.

6.5 EROSIO

6.5.1 Introduction

The ERODE subprogram calculates the amount of radioactivity blown from the repository fields due to the erosive action of the wind. The program is essentially a modification of the WEROS (Wind Erosion) program developed by the U. S. Department of Agriculture to predict potential soil loss from the great plains region of the U. S. (Woodruff, N. D., and Siddoway, F. H. 1965). The program is the integrated result of using 30 years of soil loss data and the theoretical factors that enter into a predictive calculation. Therefore, the program has sufficient experimental base to predict reliable soil loss figures.

The original WEROS program calculates the soil loss based on the evaluation of five factors that relate to the soil and its local environment. The five factors are (see Subsection 6.5.2 for definition):

- Soil erodibility (I)
- Soil-ridge roughness (K)
- Climate (C)
- The unsheltered travel distance across the field (L)
- Vegetation (V)

The influence of these factors on soil loss can be expressed in a functional form and were originally read from tables. With the development of a computer program the tables are stored as data arrays in the program itself. The soil loss is computed by an equation of the form:

$$E = I * K * C * f_1(L) * f_2(V)$$

The soil loss, E in tons/acre/year, is then multiplied (with appropriate dimensional factors) by the duration of the wind (years), area of the field (m^2), percentage of soil lofted (dimensionless), and nuclide concentration (uCi/gram of soil) from UNSAT, to obtain the amount of radioactivity by nuclide type that is used as input to ATMOS. Since the main purpose the EROSIO is to act as a transport path for radioactive dust into the atmosphere, the amount of radioactivity that becomes airborne from the soil loss must be determined. Unfortunately, this is not a well understood phenomenon. Estimates of the fraction lofted from blown soil range between 3 and 40 percent (Chepil, W. S., 1945). In the program, this number is left as an input that ranges from 0 to 100 percent but it is suggested that numbers greater than 40 percent not be used. The use of 100 percent would be conservative since it indicates that all of the blown soil becomes airborne which overestimates the quantity of radioactive particulate in the air. The output of the ERODE subprogram in microcuries by nuclide type is then used as input to the ATMOS subprogram.

6.5.2 Theory of Soil Loss by Wind Erosion

Soil erosion by wind forces is a complicated phenomenon depending on a variety of factors mentioned in the introduction. These five factors are the main influences affecting soil erosion by wind. The role that each of these factors play in soil erosion are discussed below.

The soil erodibility (I) is a quantity which relates to the crustiness of the soil and is also dependent on the size of aggregates in the surface soil. From field experience (Chepil, W. S., 1945), it has been discovered that aggregate sizes greater than 0.84 mm diameter do not greatly contribute to soil loss. By measuring the percent of dry soil not passing through a 20 mesh screen, the percentage of aggregates greater than 0.84 mm can be determined. This percentage is used to find the value (from a table) of the soil erodibility in tons/acre. If the field has a slope facing the dominant wind direction erosion is accelerated. This wind and knoll effect is taken into account by multiplying the erodibility factor by a number greater than or equal to 12. For slope greater than 500 ft, the accelerated erosion is so slight that a value of unity is used. For slopes shorter than 500 ft, the value of the slope measured at the midpoint is used to determine the knoll slope effect. The value is obtained by using a curve empirically developed by Woodruff and Siddoway (1965) to account for the windward knoll slope effect. This value is multiplied by the erodibility factor to give a modified erodibility factor used in the soil loss equation.

The soil-ridge roughness factor (K) is a measure of the roughness factor (K) of the soil surface due to ridges. The value of the roughness is determined by measuring the height of roughness elements on the soil surface.

The value of the roughness (K) is less than or equal to 1 and is obtained from an empirically determined curve relating ridge height to soil roughness.

To account for the local climatic conditions, a factor relating to mean annual temperature, mean annual precipitation and mean average wind speed have been included. The climatic factor (C) is expressed by the equation:

$$C = 34.483\ V^3/PE^2 \quad \text{where} \qquad (1)$$

V = mean monthly wind velocity at a height of 30 feet above ground surface for all winds in excess of 12 mpn (5.36 m/sec). PE =Thornthwaite's (1931) precipitation effectiveness index given by

$$PE = 115(P/T - 10)^{10/9}, \quad \text{where} \qquad (2)$$

P = mean annual precipitation (millimeters of rain) and T = mean annual temperature (^{o}C). The value of C was derived from continental weather observations over a number of years.

The unshielded travel distance of the wind across the field is defined as the distance parallel to the preponderant wind direction in excess of the shielded distance. To find the preponderant wind direction, the wind erosion forces must be known first. The magnitude of the wind erosion vector symbolized by r_j is defined to be:

$$r_j = \sum_{i=1}^{n} \overline{U}_i^3\ G_{ij} \qquad (3)$$

U_i = mean annual windspeed (> 12 mph) within the ith speed group. G_{ij} = duration factor expressing the percentage of time that the wind blows in the j^{th} direction within the ith speed group. The subscript i refers to the various speed groups used in climatalogical records. The subscript j, which runs from 0 to 16, refers to the 16 principal compass directions with j = 0 corresponding to due east. Normally the G_{ij} are normalized to unity so that:

$$\sum_{i,j} G_{ij} = 1 \tag{4}$$

The prevailing wind erosion direction is obtained by considering an imaginary line p in a polar coordinate system with θ corresponding to the angle between due east (θ degrees) and p. The wind erosion force for each principal direction parallel and perpendicular to p is given by:

$$F_{||} = \sum_{j=0}^{15} r_j \left|\cos \phi_j\right| \tag{5}$$

$$F_{\perp} = \sum_{j=0}^{15} r_j \left|\sin \phi_j\right| \tag{6}$$

F_{11} = wind erosion force parallel to p.

F = wind erosion force perpendicular to p.

r_j = wind erosion vector defined above in the j^{th} direction.

ϕ_j = angle between p and r_j.

The values of the trigonometric functions are always taken as positive to prevent wind erosion force vectors in opposite directions cancelling each other. Figure 6-4 is a diagram of the geometry for determining prevailing wind direction. Since the subscript j refers to a principal direction r_j must be at angle of 22.5j degrees from due east. (Principal directions are separated by 22.5 degrees). The angle between the wind erosion force vector r_j and the ray p denoted by ϕ_j is 22.5j - θ. The preponderance is defined as the ratio of parallel wind forces to perpendicular wind forces and is denoted by R: (Skidmor, 1965):

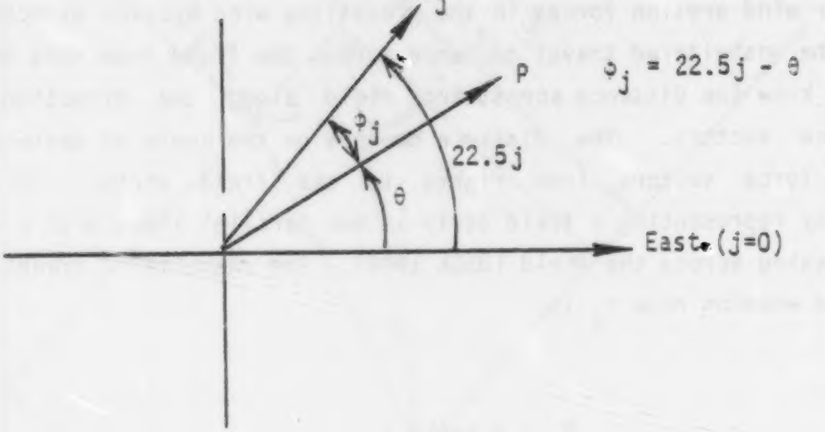

r_j
p
φ_j = 22.5j - θ
φ_j
22.5j
θ
East (j=0)

Figure 6-4. Geometry Used to Find the Prevailing Wind Erosion Direction.

$$R = \frac{F_{||}}{F_{\perp}} \tag{7}$$

By orienting the ray p through various angles θ, R may be made a maximum. The value of θ that makes R a maximum (R_{max}) is the prevailing wind erosion direction. This value of R_{max} has maximum wind erosion forces parallel to p and minimum wind forces perpendicular to p. A value of 1.0 for R_{max} indicates that there is no prevailing wind erosion direction. A value of 2.0 for R_{max} indicates that parallel wind erosion forces are twice as great as the perpendicular wind erosion forces in the prevailing wind erosion directions. To establish the unsheltered travel distance across the field from this data, it is necessary to know the distance across the field along the direction of wind erosion force vectors. The distance depends on the angle of deviation of the wind erosion force vectors from rights to the field strip. This can be visualized by representing a field strip as two parallel lines with a wind force vector r_j passing across the field (USDA 1968). The unsheltered travel distance for each wind erosion rose r_j is:

$$D_j = W \sec(A_j) \tag{8}$$

where

W = field width and

A_j = angle of deviation of wind force vector from right angles to field strip. As shown in Figure 6-5.

As shown in Figure 6-5.

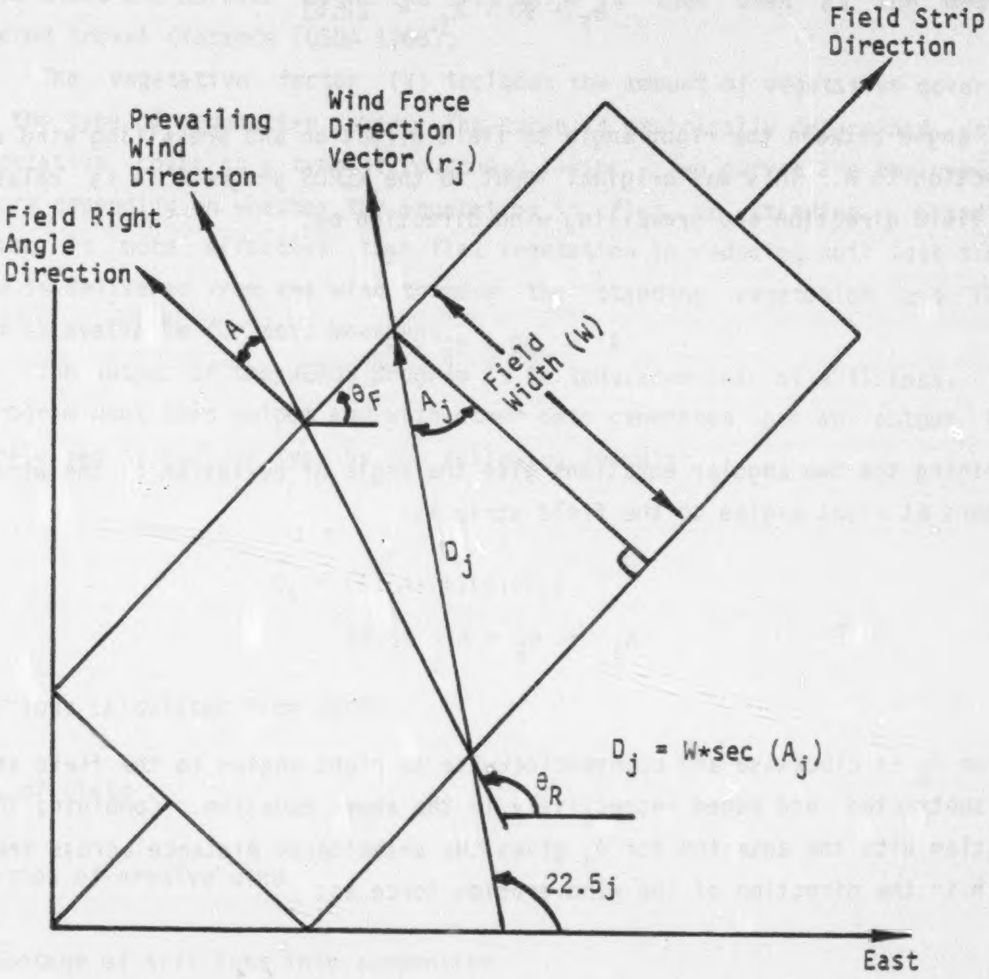

Field Strip Direction
Wind Force Direction Vector (r_j)
Prevailing Wind Direction
Field Right Angle Direction
A
θ_F
A_j
Field Width (W)
D_j
D_j = W*sec (A_j)
θ_R
22.5j
East

Figure 6-5. Geometry Used to Compute Unsheltered Travel Distance

A_j is related to the field direction and wind force angle by:

$$\theta_F + 90 - A_j = 22.5j \tag{9}$$

The angle between the right angle to field direction and prevailing wind erosion direction is A. This was original input to the WEROS program. A is related to the field direction and prevailing wind direction by:

$$A = 90 + \theta_F - \theta_R \tag{10}$$

Combining the two angular equations give the angle of deviation of the wind force vectors at right angles to the field strip as:

$$A_j = \theta_R + A - 22.5j \tag{11}$$

If the Θ_R is clockwise and counterclockwise to right angles to the field strip, A is subtracted and added respectively in the above equation. Combining the last equation with the equation for D_j gives the unsheltered distance across the field width in the direction of the wind erosion force as:

$$D_j = W \sec(22.5j - \theta_R \pm A) \tag{12}$$

By multiplying the distance by the duration of each wind erosion vector, a distribution of wind erosion forces traveling various distances to traverse the field is obtained. This distribution is then plotted as to give the percent of wind erosion forces that travel some specified multiple k of field width as a function of preponderance (R_{max}) and angle of deviation (A). The value of k for which the percentage is 50 is the median of the distribution for all wind force vectors across the field. The value of k (k_{50}) is then multiplied by the field width (W) to obtain the median unsheltered travel distance. If there are any barriers present, the median unsheltered travel distance ($k_{50}W$) is reduced by an amount 10 times the barrier height and this value is then used as the median unsheltered travel distance (USDA 1968).

The vegetative factor (V) includes the amount of vegetative cover as well as the type of vegetative cover. The curve is empirically determined using the vegetative cover as a type of roughness factor. Two curves are employed in the theory depending on whether the vegetation is flat or standing. Standing vegetation is more effective than flat vegetation in reducing soil loss since momentum is delivered from the wind to move the standing vegetation and less momentum is available for soil movement.

The output of the WEROS program is in tons/acre-year of soil loss. The ERODE program uses this output and with other data generates as an output the curies released by nuclide type by the following formula:

$$C_i = (E)(A)(t)(y)(X_i)$$

where

E = soil loss calculated from WEROS

A = area of field

t = duration of erosive wind

y = percentage of soil loss into suspension

X_i = radioactivity per gram of ith nuclide in the surface soil

C_i = radioactivity blown into atmosphere of ith nuclide

The percentage of soil loss that actually becomes suspended in the air for transport is included since not all soil loss results in suspended particles. Most of the soil loss results from saltation and creep. Few measurements of the fraction of total soil loss that actually becomes suspended have been made so that the percentage y, is uncertain. However, most researchers feel that the percentage is less than 40%. For this analysis, the percentage of soil that becomes airborne is left unspecified as a user input.

6.5.3 Computer Solution of EROSIO

The computational structure of EROSIO follows the WEROS program very closely since the soil loss computation forms the basis for the EROSIO output. Parameters specific to the wind erosion problem are read in the first step in the program. These input data are listed in the appendix in section C-5. Parameters pertinent to the original WEROS subprogram are converted from SI units to English units since the soil loss program was written for English units. The next portion of the subprogram calculates the double sum (labelled SUM) of the wind speeds over each speed group greater than 12 mph and over principal directions multiplied by the duration factor:

$$\text{SUM} = \sum_{i,j} U_j G_{ij} \tag{13}$$

where U = wind speed

G = duration factor

i = direction index, 0 through 15

j = speed group index, 0 through number of groups chosen.

A similar sum (labelled SUMG) is also performed for the duration factor:

$$\text{SUMG} = \sum_{i,j} G_{ij} \tag{14}$$

The previous expressions are used to calculate the climactic factor as shown below. In addition, another quantity (labelled SUM1) is generated by summing over speed groups to create a direction dependent variable used to compute the prevailing wind direction:

$$SUM1_i = \sum_j U_j^3 G_{ij} \qquad (15)$$

The quantity $(SUM/SUMG)^3$ represents the cube of the annual average of wind speeds greater than 12 mph for all directions and durations. This factor and the mean annual precipitation and temperature are then used to calculate the climactic factor (labelled CFCT) in the program. The original WEROS calculation of climactic factor required the use of 12 geographical maps which displayed iso-climactic factors for monthly average wind speeds temperature and precipitation. The monthly climactic factor was read from the map by noting location. The 12 monthly factors were then added to generate the yearly climactic factor which was then used as input data to the WEROS program (USDA, 1968c)^{ref} The present calculation takes advantage of atmospheric data that exists as part of the total burial package calculation to disperse with the cumbersome and time consuming graphical procedure for obtaining the climactic factor. Values for the mean annual precipitation and temperature must be greater than 0 mm and 10°C, respectively to avoid overflow errors in the program.

The next portion of EROSIO calculates parallel ($F_{//}$) and perpendicular ($F_{/}$) wind forces (labelled WNDPAR and WNDPER respectively) as a function of principal direction and a quantity labelled THSUBR. By performing a DO loop 72 times the wind forces may be calculated as a function of THSUBR in increments of 5^0 to generate a complete wind force pattern. Further accuracy is unjustified since the principal directions are in 22.5^0 increments and field strip orientation is usually not known this accurately.

By choosing the maximum value of WNDPAR from its 72 values, the maximum parallel wind force has been calculated to 5^0 accuracy. This is done in the next portion of the subprogram. The value of THSUBR which produces the maximum value for WNDPAR (labelled MAXPAR) also produces the minimum value of WNDPER (labelled MINPER) and is the prevailing wind direction. The preponderence (labelled WNDFRC) of wind forces in the prevailing wind direction is then calculated as the ratio of MAXPAR to MINPER.

The next portion of the subprogram calculates the angle of deviation of the prevailing wind erosion direction from right angles to the field strip. In the WEROS program, this is an input parameter. In EROSIO, the computed angle of the prevailing wind is used to generate the angle of deviation using the field strip angle (labelled ANGL). The field strip angle is measured from due east as 0^o. The right angle values (labelled RANGL1 and RANGL2) are measured 90^o from either side of the field strip. The difference (DIFF1 and DIFF2) between either right angle and prevailing wind angle is then computed. The smaller difference is chosen since only deviation angles up to 50^o has been correlated with wind erosion forces. Deviation angles greater than 50^o will produce an error message. The smaller difference is then used as the angle of deviation (ANG) to compute the unshielded travel distance.

At this point in the computer program, the data necessary to compute soil loss using WEROS has been generated. The WEROS subprogram calculates soil erodibility factor, roughness factor and multiplies these two values to produce an intermediate soil loss quantity (E2). E2 is then multiplied by the climactic factor to generate another intermediate quantity (E3). Next, the unshielded travel distance factor is calculated. Using the value obtained from the travel distance, E2, and E3, the soil loss is calculated from a bare, smooth field with no vegetative cover. After the various checks for vegetation types have been made, the subroutine which calculates vegetative factor is run to compute the soil loss in tons/acre/year as the WEROS output.

All tables and graphs discussed in Section 5.4.1 are included as data arrays within the EROSIO subprogram and the subprogram also has its own interpolation subroutines for input data not in the data arrays.

After the soil loss has been calculated, further modifications of the WEROS output are performed. The next calculation computes a maximum time (MAXTIM) that the wind can erode the field. This is necessary since the potential soil loss from a field can not continue indefinitely. This is accomplished by requiring the erosive depth to be less than 2.52 mm which is 30 times the height of the smallest unmoved particle of 0.84 mm. The distance is converted to time by the following calculation:

$$t_{max} = \frac{(2.52)(\rho)(1-x)}{(0.224)(E)} \quad (16)$$

ρ = density of surface soil (g/cc)

x = percentage of aggregates greater than 84 mm.

E = soil loss (tons/acre-yr)

0.224 = conversion factor

This maximum time has the dimension of years and is compared to the duration time given by the user. If the maximum time is greater (less) than the user specified time, the former (latter) is used to calculate the radioactivity released to the atmosphere.

The radioactivity released to the atmosphere (XNCOUT) is then performed as explained in subsection 5.4.2 where the factor for time is chosen as described above. The ATMOS subprogram then reads this output from the common block to use as an input source to calculate atmospheric dispersal of radioactivity.

6.6 UNSATURATED ZONE TRANSPORT SUBPROGRAM

The unsaturated zone transport subprogram, UNSAT, is used for calculation of nuclide distribution in the soil and discharge to the aquifer resulting from seepage of leachates from trenches or from other surface/near surface sources. The subprogram calculates transport resulting from leaching, water movement, and sorption/desorption. Concentration profiles of nuclides in a one-dimensional soil column are calculated. Also calculated are discharge versus time to an aquifer at the bottom of the soil column.

6.6.1 Basis for Model

UNSAT is a version of the HYDRO code developed by SAI (Amirijafari and Cheney, 1979) for calculation of transuranic (TRU) waste transport in government reservations. The code is an adaptation of an irrigation control model developed for the USEPA (King and Hanks, 1973) and later modified by Childs and Hanks (no publication).

No modifications in the problem solution method were made. Changes made were deletion of unused code sections and options and necessary changes to adopt from CDC-specific language characteristics to DEC-10 acceptable language. Note that programs which run on the DEC system will run on CDC (except for file statements) but the reverse is not generally true.

6.6.2 Discussion

This model simulates the flow of water in an unsaturated formation as a result of gravity head and capillary forces in a one-dimensional vertical heterogeneous column. The multi-layered column consists of K layers, each having its own hydraulic conductivity, soil density, thickness, and nuclide sorption characteristics. The transport of the radionuclides is based upon the flow of water. The individual nuclides can be injected into any of the K layers by dissolving each nuclide (depending on its solubility) in the water passing through the injection layer. The nuclide movement is corrected for radioactive decay as a function of elapsed time, and for retardation depending on the sorption of the nuclides on the particular rock matrix.

The general structure of the model is shown in Figure 6-6. The calculation boxes are actually loops which complete the calculation individually for each layer of the column.

The model solves for the time-dependent flow of water by stepping through time in discrete increments. The value of time and the length of the time steps are both important to the program. The important time variables are TIME, DELT, and DETT.

TIME is the actual time, starting with zero, and is the sum of all elapsed time steps. It is calculated near the end of the program.

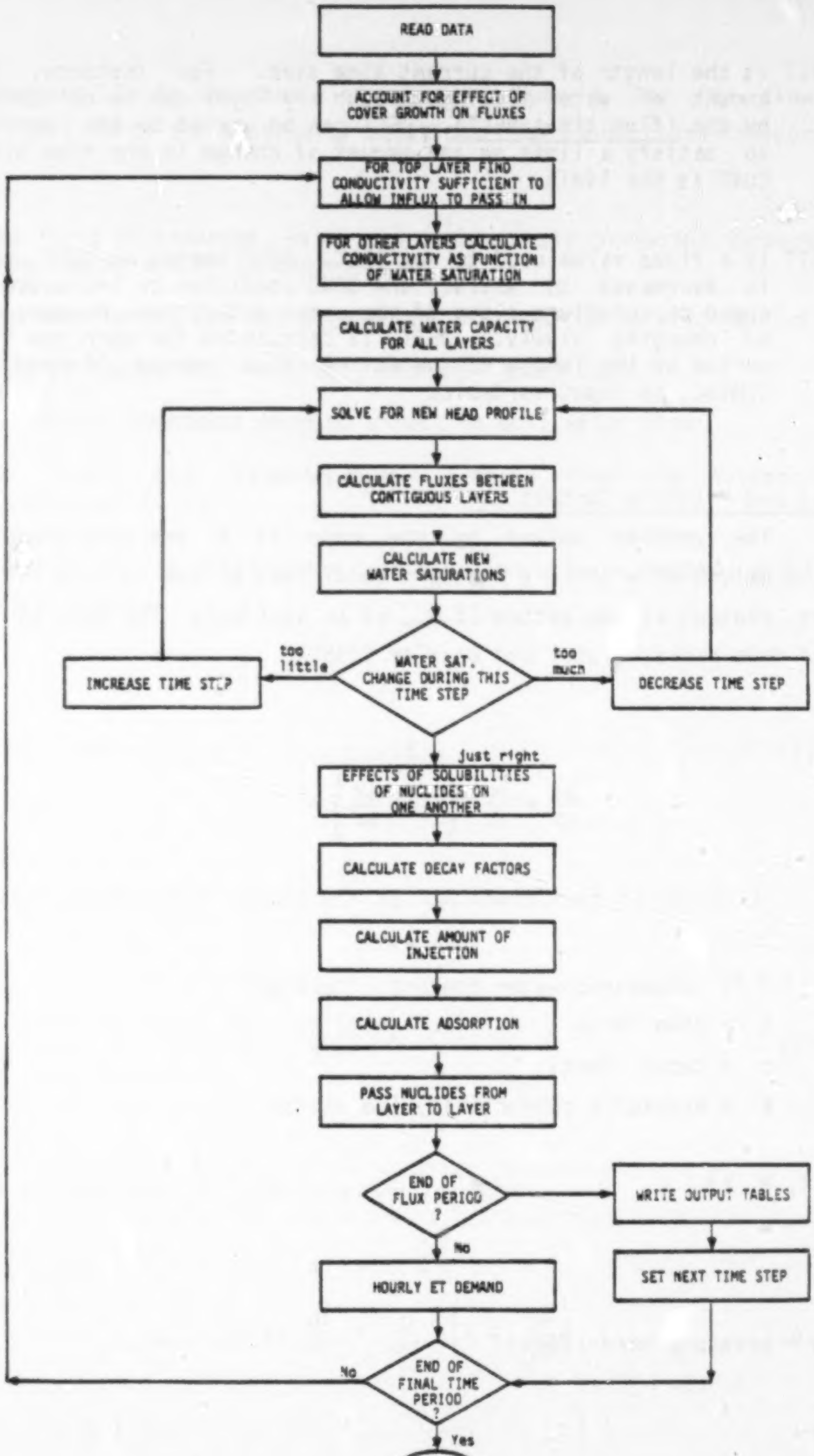

READ DATA
ACCOUNT FOR EFFECT OF COVER GROWTH ON FLUXES
FOR TOP LAYER FIND CONDUCTIVITY SUFFICIENT TO ALLOW INFLUX TO PASS IN
FOR OTHER LAYERS CALCULATE CONDUCTIVITY AS FUNCTION OF WATER SATURATION
CALCULATE WATER CAPACITY FOR ALL LAYERS
SOLVE FOR NEW HEAD PROFILE
CALCULATE FLUXES BETWEEN CONTIGUOUS LAYERS
CALCULATE NEW WATER SATURATIONS
too little
INCREASE TIME STEP
WATER SAT. CHANGE DURING THIS TIME STEP
too much
DECREASE TIME STEP
just right
EFFECTS OF SOLUBILITIES OF NUCLIDES ON ONE ANOTHER
CALCULATE DECAY FACTORS
CALCULATE AMOUNT OF INJECTION
CALCULATE ADSORPTION
PASS NUCLIDES FROM LAYER TO LAYER
END OF FLUX PERIOD ?
WRITE OUTPUT TABLES
No
HOURLY ET DEMAND
SET NEXT TIME STEP
No
END OF FINAL TIME PERIOD ?
Yes
STOP

Figure 6-6. UNSAT General Flow Chart

DELT is the length of the current time step. For instance, the amount of water flowing through any layer can be calculated by the (flux times DELT). DELT can be varied by the program to satisfy a limit on the amount of change in any time step. CONQ is the limit.

DETT is a fixed value used to set DELT. DELT begins as DETT, then is decreased to satisfy the CONQ condition or increased to speed calculations along if the water saturation happens to be changing slowly. DETT is calculated for each new flux period as the length of the entire flux period divided by TIMINC, an input variable.

Pressure and Moisture Content

The problem solved by the code is a one-dimensional soil column partially saturated with flux boundary conditions at the surface and a saturation moisture content at the bottom (i.e., at an aquifer). The general flow equation is taken from Hanks, Klute, and Bresler (1969).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\,\frac{\partial H}{\partial z}\right) \tag{1}$$

where

θ = volumetric water content (fraction)
t = time (hrs)
z = depth (feet)
K = hydraulic conductivity (no units)

The head, H, is

$$H = h + z$$

where h = pressure head (feet).

Equation (1) is the result of combining Darcy's law for flow in an unsaturated soil with the continuity equation. The assumptions inherent in the model are:

- The fluid of interest, water, is continuously connected throughout the flow region and is incompressible.
- Inertial forces are not significant as compared to viscous forces.
- Flow is isothermal, vertical, and one-dimensional.
- Biological phenomena have no effect on soil water flow.
- Air freely and instantaneously escapes from the system as water accumulates in it.

Equation (1) is transformed to one variable by a method developed by Richards (1931). Define

$$C(\theta) = \frac{\partial \theta}{\partial h} \tag{2}$$

as a soil-water differential capacity. By the chain rule of calculus

$$\frac{\partial \theta}{\partial t} = \frac{\partial \theta}{\partial h}\frac{\partial h}{\partial t} = C(\theta)\frac{\partial h}{\partial t} \tag{3}$$

Substitution of Equation (3) into Equation (1) gives

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) \tag{4}$$

where the hydraulic head ($H = h + z$) is the only dependent variable.

The finite-different form of the left-hand side term of Equation (4) is

$$C(\theta)\frac{\partial h}{\partial t} = \left(\frac{C_i^j + C_i^{j-1}}{2}\right)\left(\frac{h_i^j - h_i^{j-1}}{\Delta T}\right) = C_i^{j-1/2}\left(\frac{h_i^j - h_i^{j-1}}{\Delta t}\right) \qquad (5)$$

where the subscript i represents the depth of a node, and the superscript j represents time.

The first step in finite differencing the first term on the right side of Equation (4) is:

$$\frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) = \frac{1}{\Delta z_3}\left(K\frac{\partial H}{\partial z}\Bigg|_1 - K\frac{\partial H}{\partial z}\Bigg|_2\right) \qquad (6)$$

where the identifier 1 is the mesh increment between nodes i-1 and i, the identifier 2 is the mesh increment between nodes i and i+1, and the identifier 3 is the mesh increment between nodes i-1 and i+1. Solving for the second and third term on the right-hand side of Equation (6) yields:

$$K\frac{\partial H}{\partial z}\Bigg|_1 = \left(\frac{K_1}{\Delta z_1}\right)\left(\frac{H_{i-1}^{j-1} + H_{i-1}^{j}}{2} - \frac{H_i^{j-1} + H_i^j}{2}\right)$$

$$(7)$$

$$K\frac{\partial H}{\partial z}\Bigg|_2 = \left(\frac{K_2}{\Delta z_2}\right)\left(\frac{H_i^{j-1} + H_i^j}{2} - \frac{H_{i+1}^{j-1} + H_{i\ 1}^{j}}{2}\right)$$

where K_1 is the average of the K values corresponding to the   values at nodes (i-1, j-1), (i-1, j), (i, j-1) and (i, j), and K_2 is similarly associated with nodes (i, j-1), (i, j), (i+1, j-1) and (i+1, j). Another way of defining K_1 and K_2 that has been used is:

$$K_1 = K_{i-1/2}^{j-1/2} \quad \text{and} \quad K_2 = K_{i-1/2}^{j-1/2} \tag{8}$$

The substitution of Equations (7) and (8) into Equation (6) yields:

$$\frac{\partial}{\partial z}\left(K\frac{\partial H}{\partial z}\right) = \frac{1}{\Delta z_3}\left[\left(\frac{H_{i-1}^{j-1} + H_{i-1}^{j}}{2} - \frac{H_{i}^{j-1} + H_{i}^{j}}{2}\right)\frac{K_{i-1/2}^{j-1/2}}{\Delta z_1} - \left(\frac{H_{i}^{j-1} + H_{i}^{j}}{2} - \frac{H_{i+1}^{j-1} + H_{i+1}^{j}}{2}\right)\frac{K_{i+1/2}^{j-1/2}}{\Delta z_2}\right] \tag{9}$$

Hanks and Bowers (1962), and Hanks, Klute and Bresler (1969) assumed constant depth increments, therefore, having:

$$\Delta z_1 = \Delta z_2 = \Delta z_3$$

In this model variable depth increments are considered, hence, z_1, z_2, and z_3 are not equal and are defined by:

$$\Delta z_1 = z_i - z_{i-1}; \quad \Delta z_2 = z_{i+1} - z_1; \quad \Delta z_3 = (z_{i+1} - z_{i-1})/2 \tag{10}$$

Substituting Equations (5) and (9) into Equation (4) and substituting for H = h + z, yields:

$$\left(\frac{h_i^j - h^{j-1}}{\Delta t}\right) C_i^{j-1/2} = \frac{1}{\Delta z_3} \left(\frac{h_{i-1}^{j-1} + h_{i-1}^j - h_i^{j-1} - h_i^j + 2z}{2\Delta z_1}\right) K_{i-1/2}^{j-1/2} \qquad (11)$$

$$- \left(\frac{h_i^{j-1} + h_i^j - h_{i+1}^{j-1} - h_{i+1}^j + 2_z}{2\Delta z_2}\right) K_{i+1/2}^{j-1/2}$$

Equation (11) is the basic equation used in the interaction scheme of the model for obtaining head and moisture content profiles.

The model works with a pressure versus moisture content characteristic typical of soils and sketched in Figure 6-7. To avoid problems or asymptotes, cut-off values at the high and low end of the scale are defined and logic in the program represents the curve as a constant at either end (see Figure 1). The curve is stored as a table and is the basis for generating $C(\theta)$. Also stored is a conductivity versus moisture content characteristic curve. Individual layer conductivities are calculated by multiplying a conductivity factor times the characteristic. The factors are input for each layer as a part of the soil column data.

Calculation of Q

Water flux, Q, through layers within the column, is calculated after the tridiagonal matrix solution yielding the head values, H, for each layer. The formula used is:

$$Q = C \frac{\Delta H}{\Delta d} \cdot t \qquad (12)$$

where C is conductivity, H is head (pressure head plus gravity head in feet, d is distance in feet, and t is length of the time step in hours. In particular, Q (J), the flux at any layer, J, is always the flow between layer J-1 and layer J. Positive Q is flow downward from J-1 to J; negative Q is flow from J to J-1. C is an average conductivity defined as:

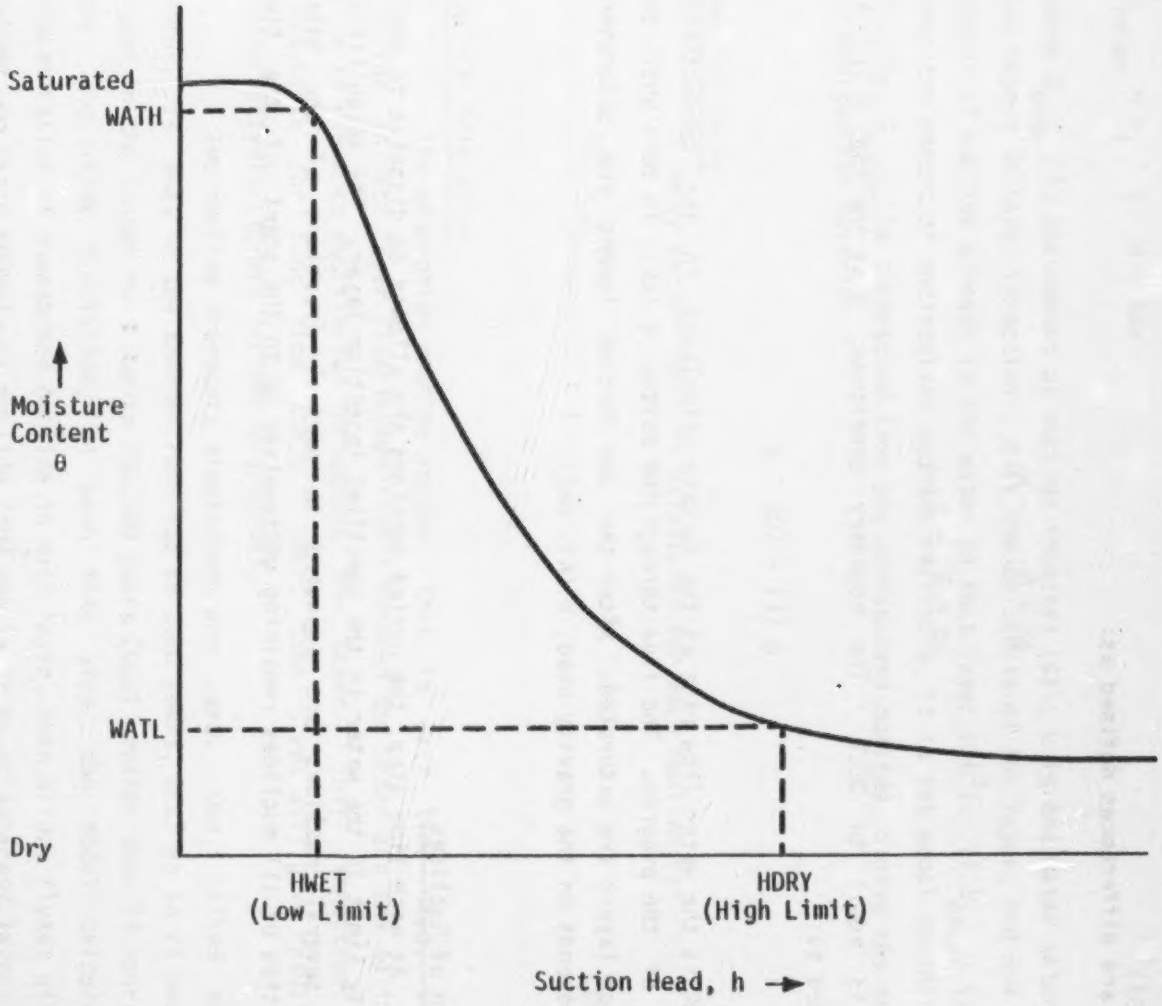


Figure 6-7. Sketch of Head versus Moisture Content for Soil

$$C = \frac{C_{J-1} + C_J}{2} \tag{13}$$

H and d are differences defined as:

$$\Delta H = H_{J-1} - H_J$$

$$\Delta d = D_J - D_{J-1}$$

and t is equal to DELT. The boundary condition, Q at the top, Q (1), is calculated as:

$$Q\ (1) = EOR \cdot t$$

where EOR is the water flow rate at the surface calculated in the conductivity section of the program. The flux through the bottom, Q (KK), is zero until the two bottom layers are saturated. After the two bottom layers are saturated, Q (KK) depends on the gravity head, H (K), only.

Injection of Nuclides

At each time step, the buried nuclides are allowed to dissolve to their solubility limit in the water in the specified injection layer. The solubilities of the several nuclides are adjusted to partial fractions of the total solubilities of all nuclides remaining undissolved up to the start of the time step:

$$P_i = \frac{S_i}{\sum_{I=1}^{N} S_i} \tag{17}$$

where P_i is the partial solubility (fraction), S_i is an individual solubility

(Ci/ft^3), and n is the number of nuclides present at that time. The amount of a nuclide injected into the column is:

$$S_{enter} = P_i \cdot W \cdot d - RAW \qquad (18)$$

where S_{enter} is the amount of nuclide injected (Ci), W is the water saturation in the injection layer (fraction), d is the thickness of the layer, and RAW is the amount of nuclide already in the water in that layer (ft^3). If S_{enter} is greater than the amount of undissolved nuclide available, it is set equal to that amount. Finally, S_{enter} is subtracted from the undissolved nuclide to give the new amount of undissolved material.

Nuclide Decay

A decay factor (DEC) is calculated for each nuclide by:

$$DEC = 2^{-T/t} \qquad (19)$$

Nuclide Adsorption

The adsorption routine assumes that in each time step, the total nuclide in each layer distributes itself between the water and the solid, and is able to reach an equilibrium throughout the layer. This assumption is most reasonable for long time steps. Short time steps will give results erring conservatively (toward farther migration).

Two nuclide transport simulations are used. One, called short-time model, is used in the shorter runs (up to 1000 years, DELT up to 24 hours), the other in the longer runs (up to 250,000 years [DELT greater than 24 hours]). In the short-time simulation, at each time step, the model calculates the concentration of unadsorbed nuclide in each layer, then allows fluxes within the column to carry amounts of nuclide from one layer to an adjacent layer. In this way, the nuclide "front" can advance only one layer per time step. In the long-time model, the calculations of unadsorbed nuclide are repeated within each time step as the nuclide is passed from layer to layer, allowing the "front" to pass through the entire column in one time step. The choice of short or long-term model is made on the basis of length of time step and layer thickness depending on conductivity.

For each nuclide an adsorption equilibrium constant is given for each layer of the column as input data. The distribution coefficient, K_d, is defined as:

$$Kd = \frac{\frac{RAS}{Wts}}{\frac{RAW}{V_w}} \qquad (20)$$

where RAS is the nuclide sorbed to the solid in curies, Wt_s is the weight of the solid (in grams), and V_w is the volume of the water (in milliliters). Since the nuclide in water, plus the nuclide on the solid, is the total nuclide in the layer, RAW, and RAS can be found independently:

$$RAW = \frac{RNCLD \cdot Kd}{\cdot \frac{WTS}{V_w}} + 1 \qquad (21)$$

$$RAS = \frac{RNCLD}{1 + \left(\frac{1}{Kd} \cdot \frac{wts}{V_w}\right)} \qquad (22)$$

where RNCLD is the total nuclide in the layer.

In this model the nuclides are not adsorbed permanently. It is assumed that the nuclides will be desorbed from the rock. Equations (21) and (22) allow both adsorption and desorption, but the rate of desorption may not be the same as adsorption, so another variable SORPFC is read as input data and is used to specify the amount of RAS which is unavailable for desorption:

$$RAW = \frac{(RNCLD - (1\text{-}SORPFC) \cdot RAS) \cdot Kd}{\frac{wts}{Vw}} + 1 \qquad (23)$$

$$RAS_{new} = \frac{RNCLD - (1\text{-}SORPFC) \cdot RAS}{1 + \left(\frac{1}{Kd} \cdot \frac{wts}{Vw}\right)} + (1\text{-}SORPFC) \cdot RAS_{old} \qquad (24)$$

So a SORPFC=1 means all sorbed material can be desorbed, and is available for new K_d distribution, and SORPFC=0 means all sorbed material is permanently bonded to the solid and cannot be desorbed.

After RAW is found, RAWCON, the concentration of nuclide in water, is calculated by dividing RAW by V_w. This RAWCON is multiplied by Q to determine the amount of nuclide carried by water from layer J-1 to J. Once the amount is determined, RNCLD(J) and RNCLD(J-1) are adjusted by that amount to keep the bookkeeping correct on RNCLD. Obvious limits are imposed; no more nuclide can be taken from a layer than is there in the layer to begin with. RAWCON as a layer can be calculated with each passing step for long time calculations. The frequency of RAWCON calculations affects the rate of movement of the nuclide front.

6.6.3 Interfaces

6.6.3.1 Input

A large amount of input data is required by this subprogram. This is primarily due to the complexity of the problem it solves. The input can be classified under: Geological Data, Meteorological Data, Nuclide Data, and Program Control Data.

Geologic Data

The soil column is described as a series of layers which can differ in density, porosity, initial moisture content, and moisture conductivity factor. The conductivity factor, CONCOF, is a multiple of the water conductivities calculated in the program. So, if an interbed of material is half as conductive as the rest of the column, the layers corresponding to the interbed are given a CONCOF of 0.5 and the rest of the layers are assigned a CONCOF of 1.0.

Meteorological Data

Meteorological data consists of the precipitation, flooding, and evaporation history for the case in question. Surface water flux can be represented in three ways:

(1) Given a depth of a standing pool and surface permeability inflow rate is calculated (this is the flood scenario).

(2) Rainfall (in meters) can be given as occurring in a fixed cycle of alternating wet and dry periods. The subprogram then calculates surface moisture flux (the "V" matrix) versus time for the entire problem time length.

(3) The entire flux history (meters of rain, meters of evaporation) can be input as a time, flux matrix (i.e., read the V matrix).

Nuclide Data

Nuclide data includes half-lives, nuclide labels, and distribution coefficients for each nuclide and soil layer. The distribution coefficient is defined in Equation (20). Also included is an initial inventory that was deposited.

Program Control Data

Other data includes various parameters to activate various options and the maximum calculation time. These are defined in the code listing and will be controlled by BURYIT.

6.6.3.2 Output. Two types of output from UNSAT are used in the systems model: (1) surface soil concentrations of nuclides as a function of time and (2) discharge rate to the aquifer as a function of time. Output type (1) is used by ERODE to calculate wind loft sources and possibly by DOSE to calculate ground shine. Output type (2) is processed by the executive routine to form input for AQUIFR.

6.7 DIRECT EXPOSURE MODEL (DIRECT)

6.7.1 Basis for Model

The function of subprogram DIRECT is to calculate the external gamma dose resulting from direct exposure to undispersed waste. Example dose situations include dose to a person approaching a waste container accidently dropped from a truck, dose from a canister on a truck (with, perhaps, the container containing more than the normal quantity of radioactive material), and dose to a person standing near an open waste disposal pit.

A fairly simple approach using point kernels, exponential shielding and dose buildup factors was chosen. Three source geometries (point, line and volume) were included using, as a basis, primarily formulas from Rockwell (1956) and Foderaro (1976). It is assumed that gamma exposure predominates. This will normally be true for external dose if the source and receiver are separated by a modest distance or shield.

6.7.2 Discussion

Subprogram DIRECT incorporates separate formulations for each of the three source geometries. A computed "GO TO" statement in the subroutine directs the logic flow to the appropriate dose formation. A flow diagram is shown in Figure 6-8.

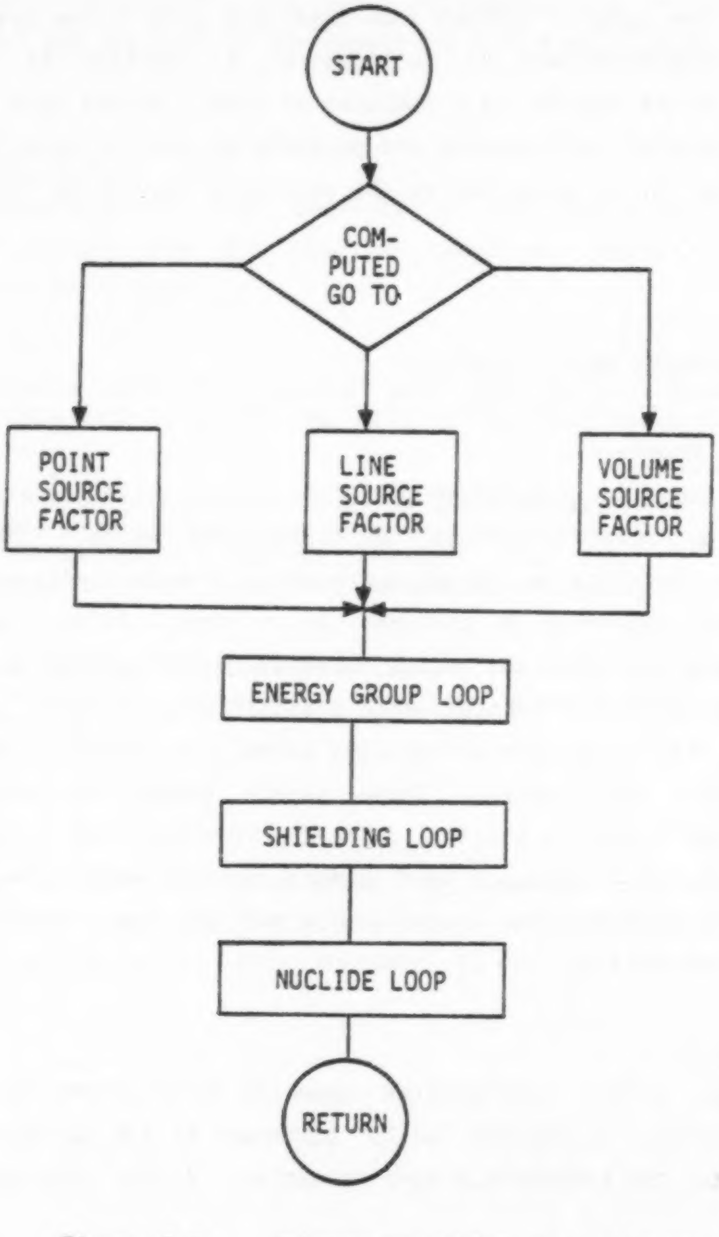

START
COM-
PUTED
GO TO
POINT SOURCE FACTOR
LINE SOURCE FACTOR
VOLUME SOURCE FACTOR
ENERGY GROUP LOOP
SHIELDING LOOP
NUCLIDE LOOP
RETURN

Figure 6-8. Subprogram DIRECT Flow Diagram

Point Source Formula

Foderaro gives the dose rate, D_u, for uncollided photons from a point source with a slab shield between the source and receiver,

$$\dot{D}_u = K(E)ES_0 \frac{e^{-b_1}}{4\pi a^2} \tag{1}$$

where
- E is the source photon energy, MeV;
- $K(E)$ is the energy flux to dose rate conversion factor (R/hr per MeV/cm^{2}sec);
- S_0 is the source emission rate, photons/sec;
- a is the distance between source and receiver, cm; and
- b_1 is the optical thickness of the shield.

In the above, the quantity $S_0/(4\pi a^2)$ is the photon flux at distance a for an unshielded point source, the quantity $(ES_0)/(4\pi a^2)$ is obviously the photon energy flux at distance a for an unshielded point source, and the quantity $(K(E)ES_0)/(4\pi a^2)$ is the dose at distance a for an unshielded point source. The attenuation factor is e^{-b_1}, where b_1 is:

$$b_1 = \sum_j X_j \mu_j , \tag{2}$$

where
- X_j is the thickness of the j-th shield, cm; and
- μ_j is the linear attenuation coefficient of the shield material

Foderaro gives the total dose rate as

$$\dot{D} = BK(E)ES_0 \frac{e^{-b_1}}{4\pi a^2} = \frac{K(E)ES_0}{4\pi a^2} \sum_{i=1}^{2} Ai\ e^{-b_{1i}} , \tag{3}$$

where the coefficients A_i and b_{1i} result from a Taylor-form expansion of the buildup factor B,

$$B = A_1\ e^{-\alpha_1 b_1} + A_2\ e^{-\alpha_2 b_1} \tag{3a}$$

In the above, A_i and α_i are Taylor-form expansion coefficients, with $A_2 = 1 - A_1$.

Line Source Formula

Foderaro (1976) and Rockwell (1956) both give a formula for the dose rate from a line source witn a slab shield parallel to the line. This shield geometry, which is not necessarily applicable here, introduces computational complexity in the form of the integral

$$K(\theta,b_1) = e^{b_1}\int_0^{\theta_1} e^{-b_1 \sec u}\, du \tag{3b}$$

which must either be evaluated numerically, or stored as a two-dimensional array. An equally likely shielding geometry, and one much easier to solve, has the receiver (exposed person) inside a wrap-around shield so that the same shield thickness applies for all angles of radiation incidence.

Foderaro (1976) gives the uncollided dose rate from a line source with shield parallel to the line,

$$\dot{D}_u = \frac{K(E)ES_\ell}{4\pi a}\; e^{-b_1}\,[K(\theta_1,b_1) + K(\theta_2,b_1)], \tag{4}$$

where S_ℓ is the line source strength, photons per second per unit length of source.

For no shield, i.e., $b_1=0$, this reduces to the line kernel $K(E)ES$ $(\theta_1+\theta_2)/4\pi a$. Choosing a worst-case geometry in which the receiver is at distance a from the center of the line source, and specifying the length of the line source as 2L, gives

$$\theta_1 = \theta_2 = \arctan\left(\frac{L}{a}\right) \tag{4a}$$

and

$$S_\ell = \frac{S_0}{2L}\,. \tag{4b}$$

Adding the wrap-around shield factor, $\sum_{i=1}^{2} A_i e^{-b_{1i}}$, which is the same as for the point source, gives the line source formula

$$\dot{D} = \frac{K(E)ES_0}{4\pi aL} \arctan\left(\frac{L}{a}\right) \sum_{i=1}^{2} A_i e^{-b_{1i}} \tag{5}$$

Volume Source Formula

Description of the dose from all possible shapes of volumetric souces and all possible source versus receiver configurations would require an infinite number of highly complicated, if derivable, formulas. Therefore, a formula was derived based on a simple, compact source geometry. The geomety is that of a cylindrical source of length 2L and diameter 2L. An analytical integration of the photon flux is possible for a receiver on an extension of the cylinder axis and at distance a from the cylinder center. The result is

$$\phi = \frac{S_0}{4\pi a^2} Fv\left(\frac{a}{L}\right) \tag{5a}$$

where

$$Fv(X) = X^2 \left\{\left[\tan^{-1}(1-X) + \tan^{-1}(1+X)\right] + 0.5(1-X) \ln\left[1+ \left(\frac{1}{1-X}\right)^2\right] + 0.5(1+X) \ln\left[1+\left(\frac{1}{1+X}\right)^2\right]\right\} \tag{6}$$

The volume source dose with wrap-around shield is thus, by analogy with the point source formula,

$$\dot{D} = \frac{K(E)ES_0}{4\pi a^2} Fv\left(\frac{a}{L}\right) \sum_{i=1}^{2} A_i e^{-b_{1i}} \tag{7}$$

The above point, line and volume dose formulas must, of course, be evaluated and the results summed for each of the nuclide contributors and, for those nuclides with multiple gamma emissions, for each different gamma energy. To reduce the data requirements and computation effort, the gamma energy treatment is performed for discrete energy groups. Ten gamma energy groups are used, with gamma energies in the respective ranges 0-0.02, 0.02-0.065, 0.065-0.15, 0.15-0.35, 0.35-0.75, 0.75-1.5, 1.5-2.5, 2.5-3.5, 3.5-4.5, and >4.5 MeV. Corresponding data for K(E), μ, A_i, and α_i are for the respective midpoint energies 0.01, 0.03, 0.1, 0.2, 0.5, 1., 2., 3., 4., and 5. MeV.

Data for five shielding materials (plus air) are included. These are aluminum, iron, lead, ordinary concrete and water. Air is assumed to occupy all space between the source and receiver not occupied by another specified shielding material, and need not be specified as a "shielding material."

A few words about nuclide treatment is in order. The quantity $EK(E)S_0$ has been divided into the parts

$$EK(E)S_0 = (EK(E)\,\frac{S_0}{C_i})C_i$$

$$= (3.7\text{x}10^{10}\ EK(E)f)\ C_i \tag{7a}$$

where C_i is the total number of curies of the nuclide in the source and f is the photon emission fraction for the photon of energy E. The quantity $3.7\text{x}10^{10}EK(E)$ has been evaluated for each gamma, then summed for the gammas in each energy group. This sum is stored for each energy group and nuclide in the two-dimensional array GE.

6.7.3 Interfaces

Subprogram DIRECT requires the following input data:

IS - source type, 1=point, 2=line, 3=volume;

R - distance from source, meters;

A - source dimension, meters (point source - not used; line souce - line half length; volume source - characteristic radius);

NS - number of shielding materials, maximum of 5;

MAT - array of shielding ID numbers (1=aluminum, 2=iron, 3=lead, 4=ordinary concrete, 5=water);

THK - array of shielding thicknesses, meters;

T - exposure time;

NI - number of radionuclides;

CI - array giving curies of each;

GE - double-dimensional array giving the quantity $3.7\text{x}10^{10}EK(E)f$ for each isotope and energy group (read from dose file along with other dose factors for DOSE routine).

Subprogram DIRECT gives the following output:

DOSE - whole body dose in Roentgens.

6.8 THE POPULATION DOSET SUBPROGRAM (DOSET)

6.8.1 Basis for Subprogram

The population and maximum individual doses from radionuclides released to the environment are calculated in subprogram DOSET, and the results are cumulated and printed in subroutine SUMDOS. Basic input to DOSET includes the radioisotope releases in terms of the time-integrated plume air concentration, the cumulated ground deposition, and the quantity of radionuclides released to the source of water. Other inputs include the population, age distribution, and food production rate (for beef cattle, milk, leafy vegetables, and other food products).

Four major dose pathways are considered, direct exposure to the radioactive cloud, direct exposure to ground contamination, inhalation (both of the cloud and resuspended particles), and ingestion of contaminated food and drink.

The DOSE subprogram is based partly on the methodology and data in NRC Regulatory Guide 1.109 (NRC 1977), partly on the methodology and data in WASH-1400 (NRC 1975), and partly on independent derivations. The method used here for calculating population dose has two major features: (1) the methodology, unlike that in Reg. Guide 1.109, is not based on a continuing steady-state radionuclide release but is instead based on a uniform release rate over time T where T may be long or short. (2) Unlike the methodolgy in Reg. Guide 1.109 and WASH-1400, the ingestion dose model for population dose is based on the production (not consumption) of contaminated foods.

Dose models are usually based on one of two release-time dependencies. The WASH-1400 model, for example, is based on a puff release while the Reg. Guide 1.109 and AIRDOS (Moore 1979) models are based on a steady-state release. The release from a shallow-land burial (SLB) site for the scenarios here may be of a very short or a very long duration. Thus, neither the puff-release model nor the steady-state release model is entirely satisfactory.

In a steady-state environment, however, the total effect of a radionuclide release is not a function of the time dependence of the release. That is, if the population is constant (neither growing nor moving), if there are no seasonal or diurnal effects, and if only the latent dose is of interest, then the total time-integrated population or maximum individual dose will not be a function of the time dependence of the release. Each curie released will have a certain effect independent of when it was released.

In this effort, two release-time dependencies were considered (1) a puff release and (2) a steady-state release over time T. Formulas for two doses are derived, (1) the total dose (integrated over infinite time and therefore independent of the release time) and (2) the first year dose. (DOSET currently calculates only the total dose). This approach is, thus, more similar to that in WASH-1400 than to that in Reg. Guide 1.109; however, the food ingestion doses in WASH-1400 were developed for only a few principal radionuclides from a reactor release. While this may be sufficient for the spectrum of nuclides in a nuclear reactor, it is not adequate for analysis of SLB events, where the WASH-1400 principal isotopes might not even be present. Therefore, the methodology developed here is similar in some respects to that in WASH-1400, but uses the more extensive radionuclides data in Reg. Guide 1.109.

Most population dose calculation procedures, including those in Reg. Guide 1.109 and WASH-1400, are consumption oriented in the sense that population doses for the ingestion pathway are calculated as the product of (1) the number of people in the local area, (2) the per-capita ingestion of food stuffs, (3) the concentration of radionuclides in locally grown foods, and (4) appropriate ingestion dose factors. This approach yields incorrect population doses when contaminated foods are exported and eaten elsewhere and when the consumption of uncontaminated imported foods is not considered.

A simpler and more consistently correct approach to the calculation of total population ingestion dose is the production oriented model used here. In this model, the population dose for the ingestion pathway is the product of (1) the quantity of food produced locally (and thus contaminated), (2) the concentration of radioisotopes in this food, and (3) the appropriate dose factors. In the production model approach, it is assumed that all foods grown are consumed by humans. The correct population ingestion doses are thus calculated regardless of local population, per capita consumption, or food export/import situations.

6.8.2 Discussion of Method

As mentioned above, doses for four major pathways are calculated. These include external dose from the contaminated ground, inhalation dose, and ingestion dose. Inhalation dose from inhalation of both particles in the radioactive plume and resuspended particles is calculated. The ingestion dose includes dose from drinking water, milk, leafy vegetables, meat (beef),and other foods (grain, root crops, fruit and nuts). The dose from leafy vegetables results from the deposition of contamination onto the plant leaves, while the dose from "other foods" results primarily from root uptake of radionuclides.

The dose formulas for the above pathways are described in the following paragraphs.

6.8.2.1 External Dose from the Radioactive Cloud. The ATMOS routine provided the time-integrated radionuclide concentration in the air, AC, in units of curie-sec/m^3. The cloud shine total time-integrated population dose for organ L is given by,

$$\mathrm{CDOSET(L)} = \sum_{I,J} \mathrm{AC(I,J)} * \mathrm{P(J)} * \mathrm{DFC(I,L)} \qquad (1)$$

where CDOSET is the dose in Rem, P is the population at distance J, and DFC is the dose factor in Rem-m^3/Ci-sec. If the duration of the radiological release, T, exceeds one year, the annual cloud shine dose is the above divided by T (in years).

Formula 1 may also be used to calculate maximum individual dose. However, for maximum individual dose, the summation is taken only over I (not J), P(J)) is 1.0, and the plume centerline AC is used.

6.8.2.2 External Dose from Contaminated Ground. The ATMOS routine provided the cumulated ground deposition of radionuclides, GC, in Ci/m^2. Note that this is not ground concentration, but is, as stated, the time-integrated deposition, i.e., the number of curies of isotope I deposited per square meter during some period of time.

Two deposition formats are considered, an instantaneous deposition of GC, Ci/m^2, and a constant deposition rate of GC/T, Ci/m^2 year for some time T (years). For the instantaneous deposition rate, the ground concentration as a function of time is equal to $GCe^{-\lambda_E t}$ where the decay constant λ_E includes leaching as well as radioactive decay. The relationship of time-integrated population dose to time t is

$$GDOSET(L) = \sum_{I,J} \frac{(1-e^{-\lambda_E t})}{\lambda_E} GC(I,J) * P(J) * DFG(I,L) \qquad (2)$$

The first year dose and total dose (for infinite time) can be calculated from the above.

For the constant deposition rate of GC/T Ci/m^2 year, the deposition rate g(t) can be written

$$g(t) = \begin{cases} GC/T & 0 \le t \le T \\ 0 & T < t \end{cases}$$

The time dependent ground concentration G is then given by the differential equation,

$$\frac{dG}{dt} = g(t)-\lambda_E G$$

For time $t \leq T$, with $g(t)=GC/T$, this yields the result

$$G(t) = \frac{Gc}{\lambda_E T}[1-e^{-\lambda_E t}] \qquad (3)$$

For time $t> =T$ The ground concentration is (4)

$$G(t) = \frac{Gc}{\lambda_E T}[1-e^{-\lambda_E T}]e^{-\lambda_E (t-T)}$$

The corresponding time integrated dose to time t is

$$\mathrm{GDOSE}(L) = \begin{cases} \sum\limits_{I,J} \left[\dfrac{t - \frac{1}{\lambda_E}\left(1-e^{-\lambda_E t}\right)}{\lambda_E T}\right] * \mathrm{GC}(I,J) * P(J) + \mathrm{DFG}(I,L) & \text{for } t \leq T \\ \sum\limits_{I,J} \left[\dfrac{T - \frac{1}{\lambda_E}\left(e^{-\lambda_E (t-T)}-e^{-\lambda_E t}\right)}{\lambda_E T}\right] \mathrm{GC}(I,J) * P(J) * \mathrm{DFG}(I,L) & \text{for } t>T \end{cases} \qquad (5)$$

Equations 2 and 5 both reduce to the following for total dose integrated to infinite time:

$$\mathrm{GDOSET}(L) = \sum_{I,J} \frac{\mathrm{GC}(I,J)}{\lambda_E} * P(J) * \mathrm{DFG}(I,L) \qquad (6)$$

These equations, with P(J) = 1 and summed over I but not J give maximum individual dose.

6.8.2.3 Inhalation Dose. There are two sources of inhalation dose, one from radionuclides in the atmospheric transport plume and one from resuspended particles. The total dose from inhalation of plume particles is given by the following:

$$\mathrm{BDOSET}(L) = \frac{\mathrm{BR}}{31536000} \sum_{I,J} \mathrm{AC}(I,J) * P(J) * \mathrm{DFB}(I,L) \tag{7}$$

where	BR	is the breathing rate, m^3/hour
	DFB	is the inhalation dose factor, Rem/curie
	AC	is the time-integrated air concentration, curie sec/m^3
	P	is the population
	31,536,000	is the number of seconds per year

In the above, I, J, and L refer to isotope location and organ, respectively. If the duration of the release, T, exceeds one year, the annual direct inhalation dose is the above divided by T (in years).

WASH-1400 (Appendix VI, pp 8-9, et. seq.) defines a resuspension factor K as the ratio of the air concentration (Ci/m^3) to the ground concentration (Ci/m^3),

$$K = 10^{-5} \exp(-0.677*t) + 10^{-9} \ m^{-1} \tag{8}$$

where t is time in years after deposition.

For a puff release, the time-integrated resuspension population dose is

$$\mathrm{RDOSET}(L) = \mathrm{BR} \times \sum_{I,J} \left\{ \frac{10^{-5}}{\lambda_E} \left[1-e^{-\lambda_E t} \right] + \frac{10^{-9}\left[1-e^{-\lambda_i t}\right]}{\lambda_i} \right\} \mathrm{GC}(I,J) * P(J) * \mathrm{DFB}(I,L) \tag{9}$$

where $\lambda_E = \lambda_I + 0.677 \text{ years}^{-1}$

For a constant deposition rate over time T, with the ground concentration given by Equations 3 and 4, the resuspension population dose is given by

$$\text{RDOSET(L)} = \text{BR}^* \sum_{I,J} \text{X(I,T,t)*GC(I,J)*P(J)*DFB(I,L)} \tag{10}$$

where

$$X(I,T,t) \equiv \begin{cases} \dfrac{10^{-5}\left[t - \frac{1}{\lambda_E}\left(1 - e^{-\lambda_E t}\right)\right]}{\lambda_E T} + \dfrac{10^{-9}\left[t - \frac{1}{\lambda_i}\left(1 - e^{-\lambda_i t}\right)\right]}{\lambda_i T} & \text{for } t \leq T \\ \dfrac{10^{-5}\left[T - \frac{1}{\lambda_E}\left(e^{-\lambda_E (t-T)} - e^{-\lambda_E t}\right)\right]}{\lambda_E T} + \dfrac{10^{-9}\left[T - \frac{1}{\lambda_i}\left(e^{-\lambda_i (t-T)} - e^{-\lambda_i t}\right)\right]}{\lambda_i T} & \text{for } t > T \end{cases}$$

For infinite t, Equations 9 and 10 both reduce to the following:

$$\text{RDOSET(L)} = \text{BR} \sum_{I,J} \left(\frac{10^{-5}}{\lambda_E} + \frac{10^{-9}}{\lambda_I}\right) \text{GC(I,J)*P(J)*DFB(J,L)} \tag{11}$$

These equations, with P(J) = 1 and summed over I but not J, are used for calculating the maximum individual dose.

6.8.2.4 Ingestion Dose. As described in Subsection 6.8.1, calculations of the population dose will be based on the production of contaminated foods rather than local consumption. Food and drink pathways considered are water, vegetables and produce, milk, and beef.

Water

If curies, Ci, are added to a stream (above ground or below ground) of flow rate F liters/year, and P people each consume U liters/year of water from this stream, Ci*P*U/F curies will be consumed. The population dose is thus (dose factor DFI)

$$DOSETW(L) = \sum_{I,J} \frac{C_i(I,J)*P(J)*DFI(I,L)*U}{F} \qquad (12)$$

If the release time T exceeds one year, the first year dose is the above result divided by T in years. This formula, with P(J) = 1 and summed over I but not J, gives maximum individual dose.

Leafy Vegetables

The ATMOS subprogram provides the cumulated ground deposition, GC, in Ci/m^2. If a fraction R (Reg. Guide 1.109, p. 68) is deposited on crops, of which area A (m^2) is planted, a total of GC*R*A curies wll be deposited onto the leaves of crops. If the crop is consumed at time t after contamination, $C(t)=GC*R*A*\exp(-\lambda_E t)$ curies would be ingested. But if there is a uniformly random time of deposition relative to harvest time, an average of

$$\overline{C}(t') = \frac{\int_o^{t'} C(t)dt}{\int_o^{t'} dt} = \frac{GC*R*A}{\lambda_E t'}\left[1 - e^{-\lambda_E t'}\right] \qquad (13)$$

curies would be consumed, where t' is the crop duration, i.e., 1/N years with N being the number of crops per year. Thus

$$\overline{C} = \frac{NGCRA}{\lambda_E}\left[1 - e^{-\lambda_E/N}\right] \text{ curies} \qquad (14)$$

and

$$DOSELV(L) = N \sum_{I,J} \frac{GC(I,J)*R(I)*DFI(J,L)*A(J)\left(1 - e^{-\lambda_E/N}\right)}{\lambda_E}$$

Equation 14 gives both the first year and total population dose for a puff release.

For a uniform deposition rate of GC/T Ci/m^2 yr over time period T, C(t) is given by the differential equation

$$\frac{dC}{dt} = \frac{GC*R*A}{T} - \lambda_E C$$

with the solution, at harvest time t = 1/N

$$C = \frac{GC*R*A}{T\lambda_E}\left[1 - e^{-\lambda_E/N}\right] \tag{15}$$

For T = 1/N, Equations 13 and 15 are the same, so Equation 14 applies. For T < 1/N, Equations 13 and 15 bracket the situation, so Equation 14 also applies. For T > 1/N, say T = M/N, C in Equation 15 is 1/M times that for Equation 13, but dose is cumulated over M growing seasons for the same total result. The first year dose, however, for M > N (T > 1 year) is N/M (i.e., 1/T) times that given by Equation 14.

Data per Reg. Guide 1.109 gives R=0.2 for all nuclides except iodine, for which R=1.0. Reg. Guide 1.109 also gives $\lambda_E = \lambda_i(yr^{-1}) + 18.4$. For $N \leq 5$, $1-\exp(-\lambda_E/N) = 1.0$. Adding a decay factor $e^{-\lambda_i t_b}$ with t_b=24 hours for delay between harvest and consumption gives

$$\text{DOSELV(L)} = N \sum_{I,J} GC(I,J) * R(I)*A(J)*DFI(I,L) * \frac{(1-\exp(-\lambda_E/N)) * \exp(-24*\lambda_E)}{\lambda_E} \tag{16}$$

The annual population dose is given by Equation 16 for $T \leq 1$ year or by 1/T times Equation 16 for T > 1 year.

The above expressions for population dose are based in the population eating all of the contaminated foods. The maximum dose individual eats a fraction VL/(CLDV*N*A) of the total foods produced, where

VL is the maximum individual leafy vegetable food consumption in kg/year

CLDV is the crop density, kg/m^2

A is the area planted to crops, m^2, and

N is the number of crops per year.

The maximum individual dose may be found by evaluating the above population dose formulas (except taking the summation, over only I, not J) and multiplying by this fraction.

Fruits, Nuts, Grains, and Root Crops

One source of contamination in all crops results from root uptake. This is the primary source of contamination for fruits, nuts, grains, and root crops. For a puff release of GC Ci/m^2 and a soil pool areal density P (240 kg/m^2 per Reg. Guide 1.109), the time-dependent soil concentration is GC exp $(-\lambda_s t)/P$ Ci/kg. As crop growth progresses, minerals (and the contamination) are drawn into the plant and used to form the fruit. Reg. Guide 1.109 gives a concentration factor, B_{iv}, Ci/kg per Ci/kg, relating the concentration in the crop to concentration in the ground. It is assumed that, as the crop grows, the incremental growth will reflect the ground concentration at the time of growth. Hence, for a growth rate of X kg/year of crop, the total curies incorporated into the crop in time t' is

$$\int_0^{t'} \frac{XGCB_{iv}}{P} \exp(-\lambda_s t)dt = \frac{XGCB_{iv}}{\lambda_s P} [1 - e^{-\lambda_s t'}] \quad \text{curies} \qquad (17)$$

The decay constant, λ_s, is the radioisotopic decay constant plus a soil sink decay constant. WASH-1400 gives 10 percent per year for Sr and 61 percent per year for Cesium. Data for other elements are needed. It is assumed here that λ_s=0.2 year^{-1}.

For a constant deposition rate of GC/T Ci/m^2 year for some time T in years, the ground concentration (Ci/m^2) is (from Equations 3 and 4).

$$G(t) = \begin{cases} \frac{GC}{\lambda_s T}\left[1 - e^{-\lambda_s t}\right] & t \le T \\ \frac{GC}{\lambda_s T}\left[1 - e^{-\lambda_s T}\right] e^{-\lambda_E (t-T)} & t > T \end{cases} \tag{18}$$

The corresponding time integral has the solution

$$\int_0^t \frac{XG(t)B_{iv}}{P} dt = \begin{cases} \frac{XB_{iv}GC}{P\lambda_s T}\left[t - \frac{1}{\lambda_s}\left(1 - e^{-\lambda_s t}\right)\right] & t \le T \\ \frac{XB_{iv}GC}{P\lambda_s T}\left[T - \frac{1}{\lambda_s}\left(e^{-\lambda_s (t-T)} - e^{-\lambda_s t}\right)\right] & t > T \end{cases} \quad \text{curies} \tag{19}$$

Defining the quantity in the appropriate integral (Equations 17 or 19), to be Q, the population dose is

$$DOSERC(L) = \sum_{I,J} Q(I,J)*DFI(I,L)*EXP(-\lambda_i t_b) \tag{20}$$

where the term $\exp(-\lambda_i t_b)$ accounts for decay between harvest and consumption. Reg. Guide 1.109 gives a value of 14 days or 0.038 years for t_b.

The above expressions for population dose are based on the population eating all the contaminated produce. The maximum dose individual eats a fraction FVG/X of the total produced, where FVG is the maximum individual produce consumption rate and X is the annual crop growth rate. The maximum individual dose may be found by evaluating the above population dose formulas (except summing only over I, not J) and multiplying by this fraction.

Milk

The population dose from milk is dependent on the quantity of contaminated milk produced, which is, in turn, dependent on the number of cows in contaminated areas. It is conservatively assumed that all milk produced is consumed as milk after a short delay time between dairy and consumer. Actually, some fraction of the milk will be used to make cheese, candy, condensed milk, etc., thereby increasing the decay time between production and consumption.

The concentration of radioisotopes on grass, as a function of time after a puff release deposition, is

$$C(t) = \frac{GCRg}{y} e^{-\lambda_E t} \quad \text{curies/kg}$$

where Rg is the deposition fraction on grass (as given by Reg. Guide 1.109) and y is the areal grass density (0.7 kg/m^2 per Reg. Guide 1.109).

Assume each cow eats Q_f kg/day (50 kg/day per 1.109). Per 1.109, a fraction fm (with dimensions of days/liter) appears in milk, so that C Q_f fm Ci/liter results. With X cows each producing Q_m liters per year, this becomes C Q_f fm Q_m X curies per year.

The total curies appearing in time t' is thus

$$\int_0^{t'} C(t) Q_f fm Q_m X dt = \frac{GCRgQ_f fmQ_m X}{g\lambda_E}\left[1 - e^{-\lambda_E t'}\right] \quad \text{curies} \qquad (21)$$

with λ_E in years^{-1}.

Similarly, for a steady-state release over time T, with the ground concentration given by Equation 18, the total curies by integration over time is

$$\frac{RgQ_f fmQ_m XGC}{y\lambda_E T}\left[t - \frac{1}{\lambda_E}\left(1 - e^{-\lambda_E t}\right)\right] \quad t \leq T$$

$$\frac{RgQ_f fmQ_m XGC}{y\lambda_E T}\left[T - \frac{1}{\lambda_E}\left(e^{-\lambda_E (t-T)} - e^{-\lambda_E T}\right)\right] \quad t > T \qquad (22)$$

Calling the quantity in the appropriate integral (Equations 21 or 22), Q, the population dose is

$$\mathrm{DOSETM(L)} = \sum_{I,J} Q(I,J)*DFI(I,L)*EXP(-\lambda_i t_b) \qquad (23)$$

Where t_b is the delay time between dairy and consumption (four days or 0.011 years per Reg. Guide 1.109).

The above expressions for population dose from milk are based on the population consuming all the contaminated milk. The maximum dose individual drinks a fraction XMILK/(XQm) of the total milk produced, where XMILK is his milk consumption in liters per year, X is the number of cows in the local area and Qm is the production rate (liters/year) per cow. The maximum individual dose from milk can be found by evaluating the above population dose formulas (except summing over I, not J) and multiplying by this fraction.

The results from Equation 21 were compared with results published in WASH 1400 (Appendix VI, page E-30). Data used were GC=1 Ci/m^2 (basis), Rg=0.5, Q_f=50, Q_m=12, X=1, Y=0.7, t'=infinity. A decay factor of EXP(=-λ_E*3 days) was used with λ_E=0.0504+λ_i days^{-1}. This yields curies per cow based on a one Ci/m^2 deposition. Dividing the respective results by 12 liters/day (cow output) and multiplying by 0.7 liters/day (WASH-1400 maximum individual consumption rate) gave the following results.

Nuclide	Calculated Value	WASH-1400 Value	Ratio
I-131	0.848	0.692	1.2
I-133	0.016	0.0042	6.8
Sr-89	0.299	0.402	0.74
Sr-90	0.396	0.588	0.67
Cs-134	5.85	4.22	1.4
Cs-136	2.48	1.42	1.7
Cs-137	5.94	4.22	1.4

Beef

The population dose from beef is dependent on the quantity of beef produced in contaminated areas. In practice, beef cattle for slaughter are often "finished" on grain in dry feed lots. It is conservatively assumed that all beef is raised on pasture grass.

As derived for milk cows, the concentration of radionuclides on grass as a function of time after a puff release is

$$C(t) = \frac{GCRg}{y} e^{-\lambda_E t} \quad \text{curies/kg} \cdot$$

Assume a steer of weight W kg eats Q_f kg/day of wet grass (50 kg/day per 1.109). If fraction F is absorbed into his flesh, the concentration X (Ci/kg) in his flesh is given by the differential equation

$$\frac{dX}{dt} = \frac{FQ_f C(t)}{W} - \lambda_e X \qquad \frac{\text{curies/kg}}{\text{day}} \qquad (24)$$

where λ_e is a biological decay constant. Solution of this differential equation with the boundary condition that X=0 at t=0 gives

$$X(t) = \frac{FQ_f GCRg}{Wy(\lambda_e - \lambda_E)} \left[e^{-\lambda_E t} - e^{-\lambda_e t} \right] \qquad \text{curies/kg}$$

If there are H animals in the herd, each of weight W, with dressout fraction f_d and slaughter fraction f_s per year, there will be $HWf_d f_s$ kg/year beef produced. The total contamination consumed as a result of the puff release is then

$$\int_0^\infty HWf_d f_s X(t)dt = \frac{Hf_d f_s FQ_f GCRg}{y\lambda_e\lambda_E} \text{ curies} \qquad (25)$$

Data for the above are as follows: herd size H is input; dressout fraction is about 0.5 kg meat per kg steer; slaughter fraction is about 33 percent per year or 0.1 percent per day based on an average life of two years for steer or heifer, an average life of nine years for calving cow (with seven calves per cow), and a little bull. Q_f is, as stated earlier, 50 kg/day, GC is input from ATMOS, Rg is element-dependent from Reg. Guide 1.109, y is 0.7 kg/m^2 (from 1.109), and λ_E is λ_i+18.4 year^{-1}.

To determine F/λ_e (in years), the solution for a steady-state problem may be derived and compared with the result and data in Reg. Guide 1.109. If there is a steady-state concentration, C, of Ci/kg in grass and a steer of weight W eats Q_f kg/day, with fraction F absorbed into flesh, the time steady-state concentration will be given by

$$\frac{dX}{dt} = \frac{FCQ_f}{W} - \lambda_e X = 0 ,$$

i.e.,

$$X = \frac{FQ_f C}{\lambda_e W}$$

Using the approach used in Reg. Guide 1.109, the concentration in meat is

$$X = F_f C Q_F$$

Thus, equating values for X,

$$F/\lambda_e = F_f W$$

The element-dependent values of F_f, in days/kg, are given in Reg. Guide 1.109.

Defining the quantity of the integral (in Equation 25) Q, the population dose from beef is

$$\mathrm{DOSEBF(L)} = \sum_{I,J} \mathrm{Q(I,J)*DFI(I,L)*EXP}(-\lambda_i t_b) \qquad (26)$$

where t_b is the delay time from slaughter to consumption (20 days or 0.055 year per Reg. Guide 1.109).

For a steady-state release over time T, the differential equation (Equation 24) can be solved with C(t) given by RgG(t)/y where G(t) is given by Equations 3 and 4. The result is a lengthy expression with λ_e appearing separately. Equation 26 will give the correct dose integrated over infinite time after a step function release. The first year dose (for T>1 year) can be estimated by multiplying that result by 1/T.

The above expressions for population dose from beef are based on the population eating all the beef produced. The maximum dose individual eats a fraction XBEEF/(H fd Wfs) of the total beef produced, where XBEEF is his beef consumption in kg per year. The maximum individual dose from beef can be found by evaluating the above population dose formulas (except summing over only I, not J) and multiplying by this fraction.

6.8.3 Application

The above methodology has been programmed in Subprogram DOSET, with cumulations over isotope, distance, pathway, organ and age group performed in Subroutine SUMDOS. Figure 6-9 is a flow diagram for DOSET. Except for a Do loop on isotope, the flow of the program is largely once-through, with the various pathways treated sequentially.

6.8.4 Interfaces

Subprogram DOSET requires the following input:

AC(I,J) - Time-integrated air concentration, Ci-sec/m^3
AREA(J) - Area associated with each radial increment, km^2
BEEF - Number of beef cattle per km^2
BIV(I) - Food concentration factor, dimensionless
COWS - Number of cows/km^2
DC(I) - Nuclide decay constant, $year^{-1}$

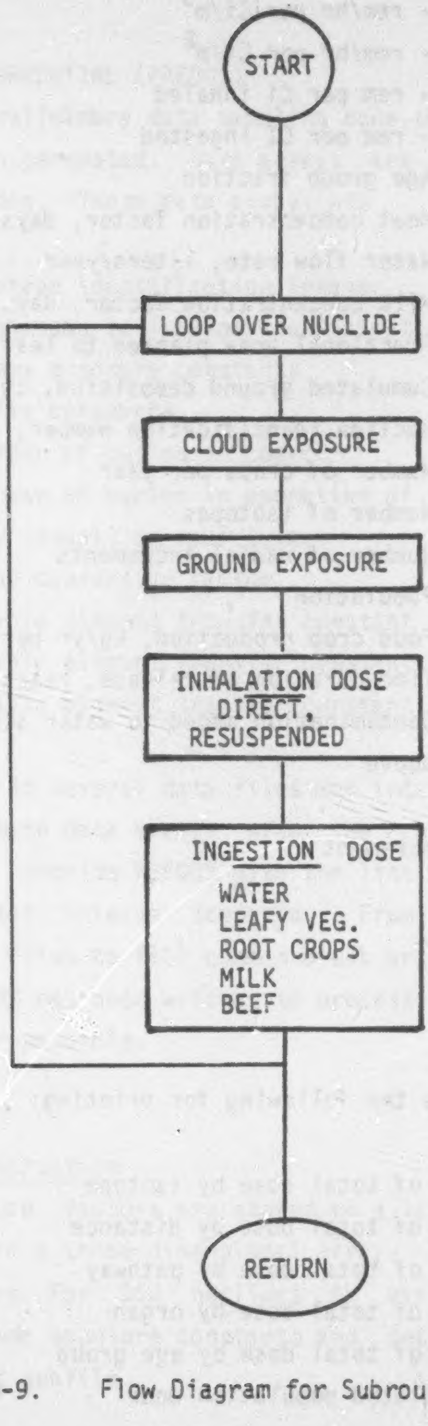

START
LOOP OVER NUCLIDE
CLOUD EXPOSURE
GROUND EXPOSURE
INHALATION DOSE
DIRECT,
RESUSPENDED
INGESTION DOSE
WATER
LEAFY VEG.
ROOT CROPS
MILK
BEEF
RETURN

Figure 6-9. Flow Diagram for Subroutine DOSE

DOSFAC(I,K,L) - Dose factor array, following units
  Cloud shine - rem/hr per Ci/m^3
  Ground shine - rem/hr per Ci/m^2
  Inhalation - rem per Ci inhaled
  Ingestion - rem per CI ingested
FAGE(M) - Age group fraction
FF(I) - Meat concentration factor, days/kg
FLOWR - Water flow rate, liters/year
FM(I) - Milk concentration factor, days/liter
FVA - Fractional area planted to leafy vegetables, dimensionless
GC(I,J) - Cumulated ground deposition, curies/m^2
IID(I) - Nuclide identification number, integer
NCPY - Number of crops per year
NI - Number of isotopes
NJ - Number of radial increments
P(J) - Population
PRODUC - Food crop production, kg/yr per km^2
T - Time duration of release, years
WC(I) - Contamination added to water stream, Ci
  Subscript for above
  I - isotope
  J - distance increment
  K - pathway
  L - organ
  M - age group

Subroutine SUMDOS cumulates the following for printing:

DOSEI(I) - Sum of total dose by isotope
DOSEJ(J) - Sum of total dose by distance
DOSEK(K) - Sum of total dose by pathway
DOSEL(L) - Sum of total dose by organ
DOSEM(M) - Sum of total dose by age group
DOSET - Cumulated population dose

All above doses are in Rem.

6.9 DATA SORTING SUBROUTINE (PREDOS)

PREDOS is a preliminary data handling code that is called as soon as a release scenario has been generated. Data arrays are processed that will be needed in other subroutines. Those data arrays are

IID - isotope identification integer
NUCNAM - alphanumeric isotope identification
GE - gamma exposure constants
DC - decay constants
CS - number of curies in source
C - number of curies in operation of interest
VD - dry deposition coefficient
DOSFAC - dose conversion factor
BIV - stable element transfer constant for vegatation
FM - stable element transfer constant for cow's milk
FF - stable element transfer constant for meat

PREDOS requires access to several data files and interaction with the executive program BURYIT to fill those data arrays with the required information. The executive program will provide PREDOS with the list of nuclides that have been identified in the selected release scenario. From this information PREDOS searches extensive data files to fill common block arrays that are to be used in other subroutines. PREDOS has been written to process large amounts of data in the most efficient manner possible.

6.9.1 Dose Table Construction

Dose equivalence factors are stored on a large disk file, NUCDAT.FIL. The dose information is in a three-dimensional array. This data base contains dose equivalence factors for 350 nuclides in each of 8 seperate subfiles. Additionaly there are gamma exposure constants and decay constants listed for each nuclide in the first subfile.

Any particular dose equivalence factor is defined by

i = the nuclide index
j = the pathway index
k = the organ index
a = age group index

6.9.1.1 Nuclide Indexing (i). Every set of dose equivalence factors is indexed by nuclide name, and accompanying ID number. The number is composed of the atomic number, Z, the isotope number, and a metastable flag. The metastable flag is a zero for ground state isotopes and unity for metastable isotopes. All of the isotopes are listed sequentially by their ID number.

6.9.1.2 Organ Indexing (k). For every pathway and every nuclide, the dose equivalence factors are given for the total body and eight organs. The organs are bone, liver, kidney, gonad, lung, GI tract, thyroid and skin. Not evey isotope and pathway will result in a dose to every organ. In a case that no dose to a particular organ is recorded, the dose factor is zero. For some pathways, there is no dose from a certain nuclide. In those instances, the dose equivalence column has been left blank.

k	organ
1	total body
2	bone
3	liver
4	kidney
5	gonad
6	lung
7	GI tract
8	thyroid
9	skin

6.9.1.3 Pathway and Age Group Indexing (j). Data for eight specific pathways in included in NUCDAT.FIL. Two cases of external exposure are defined: surface skin and closed immersion. Two cases of internal exposure are defined, inhalation and ingestion. Three age groups are also defined to account for the difference in doses due to age.

j	pathway	a	age group
1	cloud immersion	1	child
2	surface shine	2	teen
3	inhalation	3	adult
4	ingestion		

It should be understood that when the dose arises from an external pathway, the resulting dose is age independent.

6.9.1.4 Sequential Ordering. Data in the disk file NUCDAT.FIL are in sequential order to meet possible computer system compatibility reqirements. In the event that the disk file is altered in a way that disturbs the sequential ordering, erroneous results could be produced without any warning. To prevent this, a sequential checking routine is included in PREDOS. In the event that a nuclide becomes disordered in any of the pathway subfiles, error flags will occur.

To check the sequential order of a recently-altered file, a job control (JC) index can be set to provide a sequential scan of the nuclide lists. At the present time, the JC index is set with a NAMELIST instruction, but this may be modified.

6.9.2 Information Base

The external pathway dose equivalents were compiled from a listing in the Light Water Breeder Reactor Program EIS (ERDA 1976). These factors are included in Table IX.H-4 of Volume 4, and were generated from the EXREM III code. Internal pathway dose equivalents were compiled from Hoenes and Soldat, "Age-Specific Radiation Dose Factors for a One-Year Chronic Intake," (NUREG 1977). This data was calculated according to the ICRP 2 model of ingestion pathways.

Gamma exposure constants are interpolated for every given energy value, based upon the figures given in Foderaro (1977). Gamma exposure constants are used to calculate the energy constant GE value, for analysis of direct exposure pathways.

Other data arrays are based on information in the event scenario.

6.9.2.1 Methodology for External Exposure Pathways. Data included for pathways 1 and 2 are generated from the EXREM III computer program. For each radionuclide, the code considers exposure from beta, positron, electron, X- and gamma radiation.

Air Immersion Pathway. Additional information is included for nuclides not listed in the EXREM III data bank. The dose to the total body from radiation when measured at the body surface can be calculated using:

$$D = \left(\frac{3600}{2}\right)\left(\frac{K_0K_1}{K_2d_a}\right)\sum_{i=1}^{N_r} f_iE_iX_i \qquad (1)$$

K_0 = 3.7×10^{10} dis/sec
K_1 = 1.6×10^{-6} ergs/MeV
K_2 = 100 ergs/gm/rad
d_a = density of air = 1293 gms/m^3
N_r = photons emitted per dis
f_i = probability of emission of i-th photon
E_i = energy of i-th photon
X_i = concentration of nuclide Ci/m^3
3600 = seconds per hour
1/2 = 1/2 sphere

This formula makes several assumptions that will over estimate the external dose received, resulting in a conservative estimate of the actual gamma dose.

1. Assuming an infinite cloud volume biases the gamma dose upwards,
2. A uniform density cloud is seldom encountered,

3. The dose at the body surface is considerably higher than the dose to the critical organs.

To obtain a skin dose, the additional exposure due to beta particles must be added to the gamma dose. The beta skin dose can be calculated using:

$$D = 3600\alpha D_\infty^* \left[c^2\left(3 - \exp\left(\frac{1-vd}{c}\right)\right) - \frac{vd}{c}\left(2 + \ln\left(\frac{c}{vd}\right)\right) + \exp(1 - vd)\right] \quad (2)$$

c = energy dependent parameter
= normalizing constant
D_β = dose rate to surface body from beta emitters in an infinite cloud (rem/sec)
v = absorption coefficient (cm^2/gm)
d = depth from surface, expressed in (mg/cm^2)
(assumed to be 4 mg/cm^2 to correspond to the inert layer of skin)
(Salde 1968)

$$\alpha = \frac{1}{3c^2 - (c^2 - 1)e} \quad (3)$$

$$D_\infty = 0.13\bar{E}_\beta X \quad (4)$$

$$V = \frac{37.2}{(E_0 - 0.036)^{1.37}} \quad (5)$$

	energy parameters
$c = 3.0$	$E_0 < 0.17$
$c = 2.0$	$0.17 \leq E_0 \leq 0.5$
$c = 10.5$	$0.5 \leq E_0 \leq 10.5$
$c = 1.0$	$1.5 \leq E_0$

(Trubey 1977)

E_0 = maximum beta energy
X = concentration of beta-emitters in cloud (Ci/m^3)

$$\bar{E}_\beta = \begin{array}{c}\text{Average}\\ \text{Beta}\\ \text{Energy}\end{array} = \begin{Bmatrix} 0 \text{ if } E_0 \le 0.036 \text{ MeV} \\ 1/3\ E_0\ (1\text{-}0.02\ z)\ (1\_0.25\ E_0) \text{ if } E_0 > 0.036 \text{ MeV} \end{Bmatrix}$$

The skin dose, the total body dose from gamma exposure was assumed to be the dose to other organs except the skin dose.

Dose from Surface Contamination Pathways.

The dose rate from a surface deposit of gamma-emitting nuclides is calculated from a plane source formula

$$D = \frac{K_o C}{10^4} \sum_{i=1}^{N_i} f_i C_i \qquad (6)$$

where K_0 = 3.7×10^{10} dis/sec-Ci
N_r = number of photons per disintegration
f_i = probability of i-th photon being omitted
C = concentration of the surface deposit
10^4 = conversion factor of cm^2 to m^2
R_i = energy-dependent conversion factor relating the dose rate from a photon of a particular energy being omitted from an infinite plume source (rem/hr/r/cm^2sec)

R_i is calculated using

$$R_i = \frac{K_1}{2} E_1(\mu_{ai} \rho_a S) \qquad (7)$$

where K_1 = dose rate conversion defining rem/hr from two photon of energy E_1 person/cm^2

$$E_1(x) = \int_x^\infty \frac{e^{-t}}{t}\, dt \qquad (8)$$

E_1 = unshielded flux from a unit surface source (cm^2 sec)
u_{ai} = absorption coefficient of photon with given energy (cm^2/gm)
$_a$ = density of air 1.293×10^{-3} gm/cc
S = perpendicular distance from surface deposit (taken to be 100 cm)

(Rockwell 1956)

6.9.2.2 Methodology for Internal Dose Pathways. Dose factors for internal dose pathways were obtained from Hoenes and Soldat (1977) with the exception of the dose factors for the gonad dose. These factors are important because of the genetic consequences. Gonad doses were obtained from ICRP 30 and are summarized in the last chapter of this section.

General Format.

$$D_{aipj} = K_{ipj} P_{aipj} \sum_a P_{aipj} \qquad (9)$$

D = dose commitment factor
a = age group index
i = nuclide index
p = pathway
j = organ index
K_{ipj} = age independent constant
P_{aipj} = portion of dose commitment factor which is dependent on age group (a) nuclide (i), pathway (p), and organ (j).

(Hoenes 1977)

There are different dose commitment formulas used to calculate the dose to the GI tract, and for cases involving noble gases. These two special cases are described in Subsections on GI Tract and Nobel Gases.

Age-independent Constants

Ingestion Pathway

$$K_{i4j} = [18.7 * f_u/(T_1 * \lambda_e^o)^2]_{ij} \tag{10}$$

f_u = fraction of ingested nuclide reaching the organ of interest
T_1 = time of intake (given as 1 year)
λ_e^o = effective decay constant (1/day) for the organ of interest
18.7 = (22.2 dpm/pci)(5.26×10^5 min/y)(1.602×10^{-8} (s-rad)/MeV)(10^3 mRem/Rem)
4 = ingestion pathway index

Inhalation Pathway for Soluble Nuclides

$$K_{i3j} = [18.7 * f_a/(T_1 * \lambda_e^o)^2]_{ij} \tag{11}$$

f_a = fraction of inhaled nuclide reaching the organ of interest
i = soluble nuclide index
3 = inhalation pathway index
j = organ index

Inhalation Pathway for Insoluble Nuclides

$$K_{i'3j} = \left[\frac{0.0064\ \lambda_B^L\ f_2'}{T_1(\ ^{o}_{e} - \ ^{L}_{e})}\right]_{i'j} \tag{12}$$

f' = fraction of inhaled nuclide transferred from blood to organ of interest
λ_B^L = biological decay constant for the lung
λ_e^L = effective decay constant for the lung
0.0064 = (2.22 dpm/pCi)(1.44×10^3 min/d)(1.602×10^{-8} s rate/MeV) (10^3mRem/Rem)(1/8) fraction remaining in lung

λ_e^o = effective decay constant for organ of interest
i' = insoluble nuclide index
3 = inhalation pathway index
j = organ index

(Hoenes 1977)

Age-dependent Constants. For computational purposes the total population is partitioned into three distinct age groups. Dose commitments are calculated for the times during which an individual is a child, a teen, and an adult, and the results are summed. A complete discussion of the methodology is given in Hoenes and Soldat (1977).

If the intake occurs when the individual is an adult, the dose commitment during infancy, childhood and during the teens is zero. For ingestion and inhalation of soluble nuclides,

$$P_{3ipj} = \left[\frac{E}{m}_3 [T_1 * \lambda_e^o - \exp(-(T_A - T_1)\lambda_e^o) + \exp(T_A \lambda_e^o)]\right]_{ipj} \qquad (13)$$

$(E/m)_3$ = ratio of effective absorbed energy to mass of the organ of interest for an adult
T_A = total time over which dose commitment is calculated (50 years)
T_1 = time of intake (one year)
3 = index for adults
p = 3 or 4 for inhalation or ingestion, respectively

(Hoenes 1977)

For inhalation of insoluble nuclides,

$$P_{3i'pj} = \left(\frac{E}{m}\right)_A \left[T_1 \cdot \lambda_e^L - \exp\left[-(T_A - T_1) \cdot \lambda_e^L\right] + \exp\left[-T_A \cdot \lambda_e^L\right]\right] \Big/ (\lambda_e^L)^2 \qquad (14)$$
$$- \left[T_1 \cdot \lambda_e^o - \exp\left[-(T_A - T_1) \cdot \lambda_e^o\right] + \exp\left[-T_A \cdot \lambda_e^o\right]\right] \Big/ (\lambda_e^o)^2$$

READEX FICHE

3 = index for adults
i' = index for insoluble nuclides
p = 3 or 4 for inhalation or ingestion

Noble Gases. Dose to the lung from inhalation of noble gases

$$D_{ai3,6} = (G_{aio}\ E_{ai})_{3,6} \tag{15}$$

E_{ai} = energy for disintegration absorbed in lung (MeV) for age-group a and nuclide i
G_{ai} = constant determined by age-specific biological parameters, listed in Hoenes and Soldat (1977)
3 = inhalation pathway index
6 = organ index for lung

Dose to the GI Tract.

Ingestion

$$D_{ai4,7} = 0.0256\ Y'_a\ f^*\left(\frac{E}{M}\right)_a\ \exp(-\lambda_R t'_a) \tag{16}$$

Inhalation

$$D_{ai3,7} = 0.0256\ t'_a\ f^* f_a\left(\frac{E}{M}\right)_a\ \exp(-\lambda_R t'_a)$$

Y'_a = days of travel time in LLI for age group a
$(E/m)_a$ = ratio of effective absorbed energy to mass of the constants of LLI for age group a
$_R$ = radiological decay constant
t'_a = travel time to LLI for age group a
f^* = $1-f_1$ = fraction of radionuclide remaining at entrance to LLI
f_a = fraction of inhaled nuclide reaching the LLI
7 = organ index for GI tract
3 = inhalation pathway index

4 = ingestion pathway index

Daughter products may contribute significantly to the dose received and were included in the calculations. For a more detailed discussion see Hoenes and Soldat (1977).

Dose to the Gonads.. The age dependent dose committment to the gonads was not calculated. Instead, the recent ICRP Report #30 was used to provide a committed dose equivalent to various target organs for every nuclide. The committed dose equivalents have been transformed from sieverts/becquerel to rem/pCi. For a discussion of the method used in the calculation of the committed dose equivalents refer to ICRP 30 (1978).

6.9.2.3 Gamma Exposure Constants. Gamma exposure constants loaded in the gamma exposure (GE) array are calculated by

$$GE = k(E)(\text{Energy})(\text{Yield})(3.7\text{x}10^{10})$$

Values of k(E) were obtained from Foderaro (1976). These constants were calculated as follows:

$$D(R/hr) = 6.57\text{x}10^{-5}\left(\frac{\mu}{\rho}\right)_{air} E\phi(E) \tag{17}$$

E in MeV
$\phi(E)$ in cm(-2)sec(-1)
$(\mu/\rho)_{air}$ in cm^2gm^{-1}

GE values are grouped into ten energy-dependent levels and used in the DIRECT subprogram.

6.9.2.4 Stable Element Transfer Constants. To calculate the dose to humans from the release of radionuclides into the environment, the elemental intake of various elements is required. These intakes are assigned in subroutine STABLE as Stable Element Transfer Functions. These values are obtained from NRC Regulatory Guide 1.109 (1977).

6.9.2.5 Decay Constants. Decay constants for every radionuclide are stored in the first subfile of NUCDAT.FIL. The decay constant array DC(I) is filled along with the dose factor array DOSFAC(I) by subroutine DSSFAC. The decay constants are listed in terms of years^{-1}, and were compiled from many sources, including the Knolls Atomic Power Labratory Chart of the Nuclides.

6.9.3 Interfaces

6.9.3.1 Interfaces with Data Base. All of the nuclide data is contained in the large disk file NUCDAT.FIL. There are eight dose pathway subfiles, corresponding to the eight pathways listed in section 6.2.1.3. In each subfile, information is listed with the correct nuclide identifiers, IID and NUCNAM. The nuclides are listed sequentially in each of the subfiles according to the IID number. Non-pathway dependant information is listed only in the first subfile, to prevent wasteful duplication of cpu time. The array filling routines are set up to read non-pathway dependant information only from the first subfile.

6.9.3.2 Common Block Data. The function of PREDOS is to fill data arrays that are needed in other subprograms. Because of the large amount of data required from each nuclide, it is not practical to store this information internally or to fill up the core memory with data from every possible nuclide. In order to be as efficient as possible, the required data must be selectivly obtained from the data base for only the nuclides identified in the particular release scenario being run.

6.9.3.3 Output. PREDOS outputs a number of common block data arrays.

IID(I) Isotope identification number (6-place integer)
Columns 1 2 Atomic Number Z
Columns 3-5 Isotope Number
Column 6 Metastable Flag (0 or 1)

NUCNAM(I) Alphanumeric isotope identification number
(This is input array formatted 2A3)

DOSFAC(I,J,K) Dose conversion factors formatted 1PE9.2
I Nuclide index
J Pathway index
K Organ index

GE(I,E) Gamma exposure constants
I Nuclide index
E Energy grouping index

DC(I) Decay constant
VD(I) Dry deposition coefficient
CS(I) Number curies in source
C(I) Number curies in operation
BIV(IEL) Transfer constant for vegetation
FM(IEL) Transfer constant for cow's milk
FF(IEL) Transfer constant for meat

7. SENSITIVITY STUDIES

7.1 INTRODUCTION

The main objective of the sensitivity studies in this task is to provide information on the relative importance of various independent variables in the model and the relative importance of key independent variable interactions. Subsidiary objectives are to guide the final form of the shallow land burial systems model in terms of required input and output and the calculational approach.

With a model of the size and complexity of the systems model, it is not feasible to exercise every single independent variable of which there are hundreds. Whatever statistical sample one uses, no significant results can be generated for hundreds of variables without running thousands of computer cases. Part of the objective is then to determine a reasonable number of independent variables or sets of variables which should comprise a sensitivity study sufficient to meet the needs of shallow land burial systems analysis. Of key importance is to examine variables for which accurate data may be difficult to obtain.

7.2 METHODOLOGY

Due to the large number of variables involved in the Systems Model, initial efforts were made to truncate the number of inputs to only include variables that were believed to be important in the model. This truncation was done based on past experience with the codes, engineering judgement, and preliminary test runs of the codes.

Following the reduction, common variables were grouped to form categories such as weather, geology, etc. These categories were treated as single variables rather than as the multiple variables of which they are composed. Additionally, portions of the model and analyses which have no interaction were separated to reduce the size of the sensitivity study due to the individual rather than combined analysis of each piece.

Additional reduction of the size of the sensitivity study was made by employing statistical design of experiments techniques. Fractional factorial designs were developed which significantly reduced the number of required runs. These designs were analyzed using standard analysis of variance techniques. The results of this evaluation indicated which variables and interactions have signficant impact on the Systems Model results.

7.3 INDEPENDENT VARIABLES

In order to carry out a comprehensive sensitivity study on the Systems Model it was necessary to identify independent variables to be exercised. The key input variables normally used in the Systems Model are listed in Table 7-1. While the code uses many other variables they are generally utility flags for code control or problem mode or are insignificant to variations expected in shallow land burial system. Table 7-1 contains a rather large number of variables. Even a small fraction sample of a two level factorial design would require thousands of computer runs. This was impractical from a cost and schedule standpoint. Furthermore, such fine-structure in sensitivity results was judged too voluminous to be usable and far beyond expected analytical needs.

Two things were done to reduce the necessary cases in the sensitivity study (1) the variables were grouped into 16 variable sets, each set then being treated as one independent variable and (2) water path and air path sensitivity were separated resulting in addition of two case sets rather than multiplication.

7.3.1 Variable Groupings

Table 7-2 shows the variable groups used in the study. The combination of variables was carried out with logical groupings in mind. For instance, rain-fall, evapo-transporation and wind speed/stability frequency function were combined to form a weather group. Groupings for agriculture, geology, and others were similarly made. In other cases two or more variables were used in the model as a unit grouping because they never have an individual role. For example, in aquifer transport the problem is solved in terms of water travel time which is aquifer length divided by aquifer velocity. Thus, travel time was used as a variable group.

Table 7-1.

Key Variables Used in the Shallow Land Burial System Model

Variable Name	Description	Units
ORIENT	Nuclide quantity in trench (by nuclide)	Ci/ft^2
RAIN	Rainfall over normal wet period	ft/hr
DRY	Evapotranspiration in dry period	ft/hr
TIMWET	Duration of wet period	hr
TIMDRY	Duration of dry period	hr
F	Frequency array of wind speeds and stabilities	--
MAT	Mean annual temperature	^oC
IP	Population - distance array	# of people
SH	Stack height	m
SQ	Heat release (fires, etc)	cal/sec
FLOWR	Water turnover rate in water body	1/yr
PRODUC	Crop production	kg/km^2-yr
FVA	Fraction of land area with crops	--
NCPY	Number of harvests in a year	#/yr
BEEF	Number of cattle per km	#/km
COWS	Number of dairy cows per km	#/km
XZ	Length of aquifer	m
VZ	Velocity of aquifer water	m/sec
E1	Dispersion coefficient in aquifer	cm^2/sec
RNWV	Reciprocal equilibrium constant for nuclide sorption in the aquifer	--
JK	Number of layers in soil column under the trench	--
DD(JK)	Array of distances to soil layers from ground	

	surface	ft
CONCOF	Water flow conductivity factor by layer	--
KD(JK)	Nuclide sorption retardation factor by layer	ml/gm
SOLFAC	Nuclide solubility	gm/cc
LYR	Layer number where nuclides are buried	--
HTBR	Height of wind barrier at site (e.g., a fence, wall, trees)	m
ANGWND	Prevailing wind direction	deg
ANGL	Field angle to wind	deg
FW	Field width	m
	(FWxFL=total trench area)	
FL	Field Length	m
R	Equivalent vegetation cover	kg/m^2
KLSP	Knollslope of trench cap	%
RDGHT	Soil surface ridge height	m
RDGSP	Soil surface ridge spacing	m
RDGRGH	Soil surface roughness	m
PAG84	Amount of aggregates greater than 0.84 mm diameter	%
SAIR	Amount of soil remaining in suspension	%

Table 7-2.

Variable Sets Used in Sensitivity Testing.

Variable Set Number	Name	Variables in Set
1	INVENTORY	ORIENT
2	WEATHER	RAIN, DRY, TIMWET, TIMDRY F, MAT
3	DEMOGRAPHY	IP
4	STACK	SH, SQ
5	WATER BODY TURNOVER	FLOWR
6	AGRICULTURE	PRODUC, FVA, NCPY, BEEF, COWS
7	AQUIFER TRAVEL TIME	XZ, VZ
8	AQUIFER DISPERSION	E1
9	AQUIFER SORPTION	RNWV
10	SOIL COLUMN GEOLOGY	JK, DD(JK), CONCOF
11	SOIL COLUMN SORPTION	KD(JK)
12	NUCLIDE SOLUBIITY	SOLFAC
13	BURIAL DEPTH	LYR
14	SITE WIND RESISTANCE	HTBR, ANGWND, ANGL, FW, FL, R
15	SURFACE GEOLOGY	KLSP, RDGHT, RDGSP, RDGRGH
16	SOIL SUSPENSION CHARACTERISTICS	PAG34, SAIR

7.3.2 Air Path Variables

The air and water path were separated because there is no coupling between them in the model. With no coupling no cross-effects or interactions between the two were expected. Of course, the effect of unsaturated flow is still important since the soil column behavior is largely responsible for wind erosion inputs. The aquifer transport, however, is unimportant because of weak dependence of soil surface concentration on the amount of nuclides lost to the aquifer.

Table 7-3 lists the variable groups required for air path sensitivity and the levels used in the sensitivity tests. Note that all sensitivity testing was carried out with one nuclide. Some variables had two levels (high-low or "best-worst") and some had three. Three levels were specified where non-linear response was considered probable or where the variables were especially important.

7.3.3 Water Transport Variables

Variable groups and their levels for water transport sensitivity are listed in Table 7-4. In some cases a different number of levels were used for some variables that were also used in the air transport sensitivity. This was because of different estimated response characteristics.

7.3.4 Default Variables and Constants

For the sensitivity studies some variables were held at a constant value or were returned to a default value when not specified. These values are given in Table 7-5.

Table 7-3. Levels Used in Air Path Sensitivity.

Variable Set No.	Variable	Units	Values		
			Level 1	Level 2	Level 3
1	ORICNT	Ci/ft^2	1.0E+0	-	1.0E+0
2	RAIN	ft/hr	1.0E-7	6.0E-6	4.0E-5
	DRY	ft/hr	5.0E-3	5.0E-4	1.0E-4
	TIMWET	hr	3.0E+3	5.0E+3	7.3E+3
	TIMDRY	hr	3.0E+3	3.8E+3	1.5E+3
	F	-		See Table 3-3a	
	MAT	^{o}C	1.5E+1	1.5E+1	1.5E+1
3	IP	-		See Table 3-3b	
4	SH	m	0.0E+0	-	1.5E+2
	SQ	cal/sec	0.0E+0	-	0.0E+0
6	PRODUC	Kg/Km^2-yr	1.0E+2	1.0E+4	1.0E+5
	FVA	-	5.0E-4	5.0E-2	5.0E-1
	NCPY	yr^{-1}	1.0E+0	2.0E+0	3.0E+0
	BEEF	Km^{-2}	0.0E+0	5.0E+1	1.0E+2
	COWS	Km^{-2}	0.0E+0	1.0E+1	2.0E+1
10	JK	-	10	15	20
	DD(JK)	-		See Table 3-3c	
	CONCOF	-		See Table 3-3d	
11	KD	ml/gm		See Table 3-3d	
12	SOLFAC	gm/cc	1.0E+1	-	5.0E+1
13	LYR	-	5	-	10
14	HTBR	m	1.0E+1	-	0.0E+0
	ANGWND	deg	0.0E+0	-	5.0E+1
	ANGL	deg	9.0E+1	-	2.0E+1
	FW	m	1.0E+2	-	5.0E+2
	FL	m	1.0E+2	-	5.0E+2
	R	Kg/m^2	2.8E-2	-	2.8E-3
15	KLSP	%	0.0E+0	5.0E+0	1.0E+1
	RDGHT	m	5.0E-2	5.0E-2	0.0E+0
	RDGSP	m	1.3E-1	1.3E-1	0.0E+0
	RDGRGH	m	9.0E-2	5.0E+1	1.0E+1
16	PAG84	%	7.0E+1	4.5E+1	1.0E+1
	SAIR	%	5.0E+0	2.5E+1	5.0E+1

Table 7-3a. Weather Frequency Array F(I, J) for Air Path Sensitivity

Level 1

Velocity m/sec	0.35	1.11	2.0	2.89	4.25	6.72
Stability class						
A	0.	0.00128	0.00432	0.00397	0.00304	0.
B	0.	0.00794	0.02744	0.01214	0.00385	0.00012
C	0.	0.00899	0.00230	0.00864	0.00269	0.
D	0.01693	0.13031	0.09633	0.05126	0.04075	0.00339
E	0.10426	0.09727	0.02300	0.0308	0.00420	0.00035
F	0.12085	0.01857	0.00175	0.00012	0.00012	0.
G	0.16371	0.00724	0.00023	0.	0.0	0.

Level 2

Velocity m/sec	0.75	2.25	4.0	6.5	9.2
Stability class					
A	0.0103	0.0915	0.11	0.0473	0.00021
B	0.0021	0.0154	0.0112	0.001	0.
C	0.001	0.0154	0.0082	0.	0.
D	0.0195	0.0586	0.0370	0.0164	0.0010
E	0.0057	0.0832	0.0740	0.0257	0.0010
F	0.0430	0.0627	0.0164	0.0	0.
G	0.1182	0.0987	0.0031	0.0	0.

Table 7-3a.(continued)

Level 3

Velocity m/sec	0.67	2.46	4.47	6.93	9.61	12
Stability class						
A	0.17	0.0361	0.021	0.0135	0.0071	0.0052
B	0.17	0.0361	0.021	0.0136	0.0071	0.0052
C	0.171	0.0362	0.0211	0.0136	0.0071	0.0053
D	0.0487	0.0294	0.0226	0.0194	0.0117	0.0095
E	0.0277	0.0304	0.0429	0.0602	0.0327	0.0167
F	0.0393	0.0503	0.0597	0.0506	0.0182	0.0085
G	0.0254	0.0351	0.0382	0.0205	0.0019	0.0002

Table 7-3b. Population - Distance Array for Air Path Sensitivity.

IP(NR)

Distance Index	Distance (m)	Level 1	Level 2	Level 3
1	4E+2	5.0E+1	2.0E+1	1.0E+1
2	1E+3	5.5E+2	1.8E+2	9.0E+1
3	2E+3	1.0E+4	3.0E+2	0.0E+0
4	8E+3	1.0E+4	0.0E+0	0.0E+0
5	1E+4	5.0E+4	2.0E+4	9.0E+2
6	1.5E+4	2.4E+4	2.0E+4	5.0E+3
7	2.5E+4	5.4E+3	4.0E+4	1.0E+4
8	5E+4	0.0E+0	1.0E+4	2.4E+4
9	6E+4	0.0E+0	9.5E+3	5.0E+4
10	8E+4	0.0E+0	0.0E+0	1.0E+4

Table 7-3c. Locations of Layers for Air Path Sensitivity.

DD (JK)

Layer Index	Level 1	Level 2	Level 3
1	5.0E-1		
2	1.0E+0		
3	2.0E+0		
4	8.0E+0		
5	1.0E+1		
6	1.5E+1		
7	2.0E+1		
8	2.5E+1		
9	2.7E+1		
10	3.0E+1		
11		3.5E+1	
12		4.0E+1	
13		4.5E+1	
14		4.7E+1	
15		5.0E+1	
16			6.0E+1
17			7.0E+1
18			8.0E+1
19			9.0E+1
20			9.5E+1

Table 7-3d. Conductivity and KD Arrays in Air Path Sensitivity

	LEVEL 1		LEVEL 2		LEVEL 3	
LAYER INDEX	CONCOF	KD	CONCOF	KD	CONCOF	KD
1	1.0E+0	5.0E+0	1.0E+0	2.0E+1	5.0E-1	5.0E+1
2	↓	↓	↓	↓	↓	↓
3	8.0E-1	1.0E+1	↓	↓	↓	↓
4	↓	↓	↓	↓	↓	↓
5	↓	↓	↓	↓	↓	↓
6	↓	↓	3.0E-1	2.0E+2	↓	↓
7	6.0E-1	5.0E+1	↓	↓	2.0E-1	3.0E+2
8	↓	↓	↓	↓	↓	↓
9	↓	↓	↓	↓	↓	↓
10	1.0E+0	5.0E+0	↓	↓	↓	↓
11			5.0E-1	1.0E+2	↓	↓
12			↓	↓	1.0E-1	5.0E+2
13			↓	↓	↓	↓
14			1.0E+0	2.0E+1	↓	↓
15			↓	↓	↓	↓
16					6.0E-1	7.0E+2
17					↓	↓
18					↓	↓
19					↓	↓
20					↓	↓

Table 7-4. Levels Used in Water Path Sensitivity

Variable Set No.	Variable	Units		Values	
			Level 1	Level 2	Level 3
1	ORICNT	Ci/ft^2	5.0E-3		1.0E+0
2	RAIN	ft/hr	1.0E-2	6.0E-1	4.0E+0
	DRY	ft/hr	1.0E-3	5.0E-4	1.0E-5
	TIMWET	ft/hr		3.0E+3	7.3E+3
	TIMDRY	ft/hr	3.0E+3	3.8E+3	1.5E+3
5	FLOWR	e/yr	1.0E+12		1.0E+14
7	XZ	m	4.0E+1		2.0E+2
	VZ	m/sec	5.0E-2		5.0E-3
8	E1	cm^2/sec	1.0E-3		1.0E-5
9	RNWV	-	1.0E+0	5.0E-1	1.0E-1
10	JK	-	10	15	20
	DD(JK)			(see Table 3-3c)	
	CONCOF			(see Table 3-4a)	
11	KD(JK)			(see Table 3-4b)	
12	SOLFAC	gm/cc	1.0E+1		5.0E+2

Table 7-4a. Water Flow Conductivity Array for Water Path Sensitivity.

LAYER INDEX	CONCOF LEVEL 1	 LEVEL 2	 LEVEL 3
1	1.0E+0	1.0E+0	5.0E-1
2	↓	↓	↓
3	8.0E-1	↓	↓
4	↓	↓	↓
5	↓	↓	↓
6	↓	3.0E-1	↓
7	6.0E-1	↓	2.0E-1
8	↓	↓	↓
9	↓	↓	↓
10	1.0E+0	↓	↓
11		5.0E-1	↓
12		↓	1.0E-1
13		↓	↓
14		1.0E+0	↓
15		↓	↓
16			6.0E-1
17			↓
18			↓
19			↓
20			↓

Table 7-4b. KD Array for Water Path Sensitivity.

Layer Index	Level 1	Level 3
1	1.0E+1	1.0E+3
2	↓	↓
3	↓	↓
4	1.0E+0	1.0E+1
5	↓	↓
6	↓	↓
7	↓	↓
8	1.0E-1	1.0E+0
9	↓	↓
10	↓	↓
11	↓	↓
12	↓	5.0E-1
13	↓	↓
14	↓	↓
15	↓	↓
16	↓	1.0E-1
17	↓	↓
18	↓	↓
19	↓	↓
20	↓	↓

Table 7-5. Constant Values for Sensitivity Studies.

Constants

NR = No. of population vs distance grid points = 10

PAGE = Age distribution fractions
Child, Teen, Adult = 0.25, 0.15, 0.60

DNSTY = Soil density = 1.8 all layers

7.4 EXPERIMENTAL DESIGN

The number of cases to be run in the Systems Model sensitivity study is potentially overwhelming from a cost, time, and data standpoint. Despite the reductions discussed in Section 7.3, a significant number of possible combinations of variable values remain that could be evaluated. If all possible combinations were to be considered in the water path sensitivity study, the number of Systems Model runs required would be $3^3 \times 2^6$ or 1728. For the air path sensitivity study, the number of combinations would equal $3^6 \times 2^6$ or 46,656. Thus, further reduction was necessary in order to keep the sensitivity study at a reasonable level.

7.4.1 Approach

No reductions could be made at this point by eliminating variables, reducing the number of levels, or by additional splitting of variable groups without losing significant information. Therefore, the method chosen for further reduction in this case was the application of statistical techniques from experimental design methodology. Specifically, fractional factorial designs were developed for both the air and the water path sensitivity studies. This methodology reduces the size of the study to a manageable level.

Factorial experimental designs look at all combinations of levels of the input variables. Information gained from this technique can be used to evaluate the effect that the main variables and all their interactions have on the results. By reducing statistical information dealing with interaction effects which are felt to be insignificant, the sample size of the experiment can be reduced. The information that is lost is confounded or blended with the remaining information in a manner which prevents extraction using statistical techniques. Thus if an interaction effect, which was felt to be of little importance, is confounded with a main variable effect, the statistical effect of the main variable is really the effect of either the main variable, or the interaction, or both. No statistical test can separate the confounded pair.

In experiments where high order interactions are thought to be insignificant, sample sizes can be greatly reduced. The effects of high order interactions are confounded with the effects of the main variables. Sample sizes are reduced by fractions equal to powers of the number of levels of the variables. In experiments where the variables have multiple prime levels, as is the cases in both the air and water path sensitivity studies, the fractional factorial designs are developed by grouping variables of equal levels. The total design is simply a factorial combination of the separate designs.

A fractional factorial design is developed by equating a number of high order interactions of the variables with an identity effect. Rules are applied to develop the remaining portion of the defining contrast. Once the contrast is known, the remaining aliases of the variables and interactions can be found by a simple overlap technique. A discussion of the details of this development is found in design of experiments texts (Anderson, 1974). Some details are provided in the following sections.

7.4.2 Air Path Experimental Design

The air path sensitivity study has a total of twelve variables of which six have three levels and six have two levels. Thus, there is a potential of $3^6 \times 2^6$ or 46,656 tests of the Systems Model as stated earlier. This experiment is divided into two parts for the purpose of developing the design. The six three level variables were handled separately from the six two level variables. The design was a 1/72 replicate of the total factorial. This was defined by forming a 1/9 replicate of the 3^6 factorial and a 1/8 replicate of the 2^6 factorial designs. The final sample size consisted of 648 out of the 46,656 possible samples.

The six three level variables were covered first. Table 7-6 presents the design of a 1/9 replicate of the 3^6 factorial. The letters A through F represent the six variables. The superscript on the letter indicates the level with zero being the lowest level.

To define the contrast, two interactions must be chosen since the design is a $(1/3)^2$ replicate. The interactions selected were ABCD and CDEF. The remainder of the contrast is found by finding the following interactions. First is the interaction of the two primary interactions and second is the interaction of the first primary interaction with the square of the second primary interaction. The remainder of the interactions are just the squares of the previous interactions. It should be noted that AB^2 is equivalent to A^2B in this

Table 7-6. 1/9 Replicate of 3^6 Factorial Design.

Defining Contrast $I = ABCD = CDEF = ABC^2D^2EF = ABE^2F^2 = [ABCD]^2 = [CDEF]^2 = [ABC^2D^2EF]^2 = [ABE^2F^2]^2$

Aliases or confounding scheme

$A = AB^2C^2D^2 = ACDEF = AB^2CDE^2F^2 = AB^2EF = BCD = AC^2D^2E^2F^2 = BC^2D^2EF = BE^2F^2$
$B = AB^2CD = BCDEF = AB^2C^2D^2EF = AB^2E^2F^2 = ACD = BC^2D^2E^2F^2 = AC^2D^2EF = AE^2F^2$
$C = ABC^2D = CD^2E^2F^2 = ABD^2EF = ABCE^2F^2 = ABD = DEF = ABCD^2EF = ABC^2E^2F^2$
$D = ABCD^2 = CD^2EF = ABC^2EF = ABDE^2F = ABC = CEF = ABC^2DEF = ABD^2E^2F^2$
$E = ABCDE = CDE^2F = ABC^2D^2E^2F = ABF^2 = ABCDE^2 = CDF = ABC^2D^2F = ABEF^2$
$F = ABCDF = CDEF^2 = ABC^2D^2EF^2 = ABE^2 = ABCDF^2 = CDE = ABC^2D^2E = ABE^2F$
$AB = ABC^2D^2 = ABCDEF = ABCDE^2F^2 = ABEF = CD = ABC^2D^2E^2F^2 = CDE^2F^2 = EF$
$AB^2 = AC^2D^2 = AB^2CDEF = ACDE^2F^2 = AEF = BC^2D^2 = AB^2C^2D^2E^2F^2 = BCDE^2F^2 = BEF$
$AC = AB^2CD^2 = AC^2DEF = AB^2DE^2F^2 = AB^2C^2EF = BD = AD^2E^2F^2 = BCD^2EF = BC^2E^2F^2$
$AC^2 = AB^2D^2 = ADEF = AB^2C^2DE^2F^2 = AB^2CEF = BC^2D = ACD^2E^2F^2 = BD^2EF = BCE^2F^2$
$AD = AB^2C^2D = ACD^2EF = AB^2CE^2F^2 = AB^2D^2EF = BC = AC^2E^2F^2 = BC^2DEF = BD^2E^2F^2$
$AD^2 = AB^2C^2 = ACEF = AB^2CD^2E^2F^2 = AB^2DEF = BCD^2 = AC^2DE^2F^2 = BC^2EF = BDE^2F^2$
$AE = AB^2C^2D^2E^2 = ACDE^2F = AB^2CDEF^2 = AB^2F = BCDE^2 = AC^2D^2F^2 = BC^2D^2F = BEF^2$
$AE^2 = AB^2C^2D^2E = ACDF = AB^2CDF^2 = AB^2E^2F = BCDE = AC^2D^2EF^2 = BC^2D^2E^2F = BF^2$
$AF = AB^2C^2D^2F^2 = ACDEF^2 = AB^2CDE^2F = AB^2E = BCDF^2 = AC^2D^2E^2 = BC^2D^2E = BE^2F$
$AF^2 = AB^2C^2D^2F = ACDE = AB^2CDE^2 = AB^2EF^2 = BCDF = AC^2D^2E^2F = BC^2D^2EF^2 = BE^2$
$BC^2 = AB^2D = BDEF = AB^2CD^2EF = AB^2C^2E^2F^2 = AC^2D = BCD^2E^2F^2 = AD^2EF = ACE^2F^2$
$BD^2 = AB^2C = BCEF = AB^2C^2DEF = AB^2D^2E^2F^2 = ACD^2 = BC^2DE^2F^2 = AC^2EF = ADE^2F^2$
$BE = AB^2CDE = BCDE^2F = AB^2C^2D^2E^2F = AB^2F^2 = ACDE^2 = BC^2D^2F^2 = AC^2D^2F = AEF^2$
$BF = AB^2CDF = BCDEF^2 = AB^2C^2D^2EF^2 = AB^2E^2 = ACDF^2 = BC^2D^2E^2 = AC^2D^2E = AE^2F$
$CD^2 = ABC^2 = CE^2F^2 = ABDEF = ABCD^2E^2F^2 = ABD^2 = DE^2F^2 = ABCEF = ABC^2DE^2F^2$

Table 7-6. 1/9 Replicate of 3^6 Factorial Design (Continued).

$CE = ABC^2DE = CD^2EF^2 = ABD^2E^2F = ABCF^2 = ABDE^2 = DF = ABCD^2F = ABC^2EF^2$

$CE^2 = ABC^2DE^2 = CD^2F^2 = ABD^2F = ABCEF^2 = ABDE = DE^2F = ABCD^2E^2F = ABC^2F^2$

$CF = ABC^2DF = CD^2E^2F = ABD^2EF^2 = ABCE^2 = ABDF^2 = DE = ABCD^2E = ABC^2E^2F$

$CF^2 = ABC^2DF^2 = CD^2E^2 = ABD^2E = ABCE^2F = ABDF = DEF^2 = ABCD^2EF^2 = ABC^2E^2$

$DE^2 = ABCD^2E^2 = CD^2F = ABC^2F = ABDEF^2 = ABCE = CE^2F = ABC^2DE^2F = ABD^2F^2$

$DF^2 = ABCD^2F^2 = CD^2E = ABC^2E = ABDE^2F = ABCF = CEF^2 = ABC^2DEF^2 = ABD^2E^2$

$EF^2 = ABCDEF^2 = CDE^2 = ABC^2D^2E^2 = ABF = ABCDE^2F = CDF^2 = ABC^2D^2F^2 = ABE$

$ACE = AB^2CD^2E^2 = AC^2DE^2F = AB^2DEF^2 = AB^2C^2F = BDE^2 = AD^2F^2 = BCD^2F = BC^2EF^2$

$ACE^2 = AB^2CD^2E = AC^2DF = AB^2DF^2 = AB^2C^2E^2F = BDE = AD^2EF^2 = BCD^2E^2F = BC^2F^2$

$AC^2E = AB^2D^2E^2 = ADE^2F = AB^2C^2DEF^2 = AB^2CF = BC^2DE^2 = ACD^2F^2 = BD^2F = BCEF^2$

$AC^2E^2 = AB^2D^2E = ADF = AB^2C^2DF^2 = AB^2CE^2F = BC^2DE = ACD^2EF^2 = BD^2E^2F = BCF^2$

$ACF = AB^2CD^2F^2 = AC^2DEF^2 = AB^2DE^2F = AB^2C^2E = BDF^2 = AD^2E^2 = BCD^2E = BC^2E^2F$

$ACF^2 = AB^2CD^2F = AC^2DE = AB^2DE^2 = AB^2C^2EF^2 = BDF = AD^2E^2F = BCD^2EF^2 = BC^2E^2$

$AC^2F = AB^2D^2F^2 = ADEF^2 = AB^2C^2DE^2F = AB^2CE = BC^2DF^2 = ACD^2E^2 = BD^2E = BCE^2F$

$AC^2F^2 = AB^2D^2F = ADE = AB^2C^2DE^2 = AB^2CEF^2 = BC^2DF = ACD^2E^2F = BD^2EF^2 = BCE^2$

$ADE^2 = AB^2C^2DE = ACD^2F = AB^2CF^2 = AB^2D^2E^2F = BCE = AC^2EF^2 = BC^2DE^2F = BD^2F^2$

$AD^2E = AB^2C^2E^2 = ACE^2F = AB^2CD^2EF^2 = AB^2DF = BCD^2E^2 = AC^2DF^2 = BC^2F = BDEF^2$

$ADF^2 = AB^2C^2DF = ACD^2E = AB^2CE^2 = AB^2D^2EF^2 = BCF = AC^2E^2F = BC^2DEF^2 = BD^2E^2$

$AD^2F = AB^2C^2F^2 = ACEF^2 = AB^2CD^2E^2F = AB^2DE = BCD^2F^2 = AC^2DE^2 = BC^2E = BDE^2F$

methodology. That is $AB^2 = (AB^2)^2$. None of the interactions displayed are shown with a squared first variable by convention.

The result of Table 7-1 is developed by finding the interaction of variables and interactions that have not been involved in previous parts of the table with the defining contrast. Looking at the first row with the main variable A, the development proceeds as follows. A's interaction with the identity, I, is simply A. The interaction with ABCE is initially A^2BCD. By convention this is squared to find the interaction without a squared first term. The square of A^2BCD equals $A^4B^2C^2D^2$ which in MOD 3 equals $AB^2C^2D^2$ as shown in the table. Another example is the last term in the first row. A's interaction with $(ABE^2F^2)^2$ or with $A^2B^2E^4F^4$ equals $A^3B^2E^4F^4$ which in MOD 3 equals B^2EF which by convention equals BE^2F^2. The development continues in this manner until all interactions are covered.

Note that the main variables are not confounded with any two factor interactions. Some two factor interactions are confounded with other two factor interactions, however.

Table 7-7 is the development for the six two level variables. In this case, the design is a $(1/2)^3$ replicate which indicates that three interactions must be confounded with the identity. The variables run from G through L and the three defining interactions are GHI, JKL, and GHKL. Note that one of the resultant interactions in the defining contrast is IJ, a two factor interaction. Also note that the variable I is confounded with the variable J and that many two factor interactions are confounded with the main variables.

It was then possible to assign the actual model parameters to the experimental design variables. The result of this assignment is shown in Table 7-8. The parameters were assigned in a manner to allow the maximum information to be gained on two factor interactions which were felt to be significant. The parameter, nuclide quantity, is confounded with the parameter, stack height. Thus, one of these parameters was set constant in order to gain any information at all about the other parameter. Since nuclide quantity was a parameter in the water path sensitivity study, it was set to a constant value in this design. Interactions evaluated were as follows: AC, AD, AE, AF, AG, AK, AL, CE, CF, CG, CH, CL, EF, EG, EK, FG, FK, GK, and GL. All other interactions are felt to be insignificant or are confounded with evaluated effects.

Table 7-7. 1/8 Replicate of a 2^6 Factorial Design.

Defining Contrast I = GHI = JKL = GHIJKL = GHKL = IKL = GHJ = IJ

Aliases or Confounding Scheme

G = HI = GJKL = HIJKL = HKL = GIKL = HJ = GIJ

H = GI = HJKL = GIJKL = GKL = HIKL = GJ = HIJ

I = GH = IJKL = GHJKL = GHIKL = KL = GHIJ = J

K = GHIK = JL = GHIJL = GHL = IL = GHJK = IJK

L = GHIL = JK = GHIJK = GHK = IK = GHJL = IJL

GK = HIK = GJL = HIJL = HL = GIL = HJK = GIJK

GL = HIL = GJK = HIJK = HK = GIK = HJL = GIJL

Table 7-8. Air Path Sensitivity Study Variable Definitions.

Variable	Variable Name
A	Weather
B	Agriculture
C	Layers in soil column
D	Demography
E	Cap characteristics
F	Soil size
G	Burial depth
H	Nuclide solubility
I	Nuclide quantity
J	Stack
K	Site wind resistance
L	Retardation factor

Table 7-9. Sample Blocks for 1/9 Replicate of 3^6 Factorial.

Defining Equations

ABCD: $X_1 + X_2 + X_3 + X_4 = 0, 1, 2, \text{MOD } 3$

CDEF: $X_3 + X_4 + X_5 + X_6 = 0, 1, 2, \text{MOD } 3$

Levels of ABCD:	0	0	0	1	1	1	2	2	2
Levels of CDEF:	0	1	2	0	1	2	0	1	2
1	000000	000001	000002	000102	000100	000101	000201	000202	000200
2	000012	000010	000011	000111	000112	000110	000210	000211	000212
3	000021	000022	000020	000120	000121	000122	000222	000220	000221
4	001200	001201	001202	001002	001000	001001	001101	001102	001100
5	001212	001210	001211	001011	001012	001010	001110	001111	001112
6	001221	001222	001220	001020	001021	001022	001122	001120	001121
7	002100	002101	002102	002202	002200	002201	002001	002002	002000
8	002112	002110	002111	002211	002212	002210	002010	002011	002012
9	002121	002122	002120	002220	002221	002222	002022	002020	002021
10	010201	010202	010200	010000	010001	010002	010102	010100	010101
11	010210	010211	010212	010012	010010	010011	010111	010112	010110
12	010222	010220	010221	010021	010022	010020	010120	010121	010122
13	011101	011102	011100	011200	011201	011202	011002	011000	011001
14	011110	011111	011112	011212	011210	011211	011011	011012	011010
15	011122	011120	011121	011221	011222	011220	011020	011021	011022
16	012001	012002	012000	012100	012101	012102	012202	012200	012201
17	012010	012011	012012	012112	012110	012111	012211	012212	012210
18	012022	012020	012021	012121	012122	012120	012220	012221	012222
19	020102	020100	020101	020201	020202	020200	020000	020001	020002
20	020111	020112	020110	020210	020211	020212	020012	020010	020011
21	020120	020121	020122	020222	020220	020221	020021	020022	020020
22	021002	021000	021001	021101	021102	021100	021200	021201	021202
23	021011	021012	021010	021110	021111	021112	021212	021210	021211
24	021020	021021	021022	021122	021120	021121	021221	021222	021220
25	022202	022200	022201	022001	022002	022000	022100	022101	022102

Table 7-9. Sample Blocks for 1/9 Replicate of 3^6 Factorial (Continued).

Levels of ABCD:	0	0	0	1	1	1	2	2	2
Levels of CDEF:	0	1	2	0	1	2	0	1	2
26	022211	022212	022210	022010	022011	022012	022112	022110	022111
27	022220	022221	022222	022022	022020	022021	022121	022122	022120
28	100201	100202	100200	100000	100001	100002	100102	100100	100101
29	100210	100211	100212	100012	100010	100011	100111	100112	100110
30	100222	100220	100221	100021	100022	100020	100120	100121	100122
31	101101	101102	101100	101200	101201	101202	101002	101000	101001
32	101110	101111	101112	101212	101210	101211	101011	101012	101010
33	101122	101120	101121	101221	101222	101220	101020	101021	101022
34	102001	102002	102000	102100	102101	102102	102202	102200	102201
35	102010	102011	102012	102112	102110	102111	102211	102212	102210
36	102022	102020	102021	102121	102122	102120	102220	102221	102222
37	110102	110100	110101	110201	110202	110200	110000	110001	110002
38	110111	110112	110110	110210	110211	110212	110012	110010	110011
39	110120	110121	110122	110222	110220	110221	110021	110022	110020
40	111002	111000	111001	111101	111102	111100	111200	111201	111202
41	111011	111012	111010	111110	111111	111112	111212	111210	111211
42	111020	111021	111022	111122	111120	111121	111221	111222	111220
43	112202	112200	112201	112001	112002	112000	112100	112101	112102
44	112211	112212	112210	112010	112011	112012	112112	112110	112111
45	112220	112221	112222	112022	112020	112021	112121	112122	112120
46	120000	120001	120002	120102	120100	120101	120201	120202	120200
47	120012	120010	120011	120111	120112	120110	120210	120211	120212
48	120021	120022	120020	120120	120121	120122	120222	120220	120221
49	121200	121201	121202	121002	121000	121001	121101	121101	121100
50	121212	121210	121211	121011	121012	121010	121110	121111	121112
51	121221	121222	121220	121020	121021	121022	121122	121120	121121
52	122100	122101	122102	122202	122200	122201	122001	122002	122000
53	122112	122110	122111	122211	122212	122210	122010	122011	122012

Table 7-9. Sample Blocks for 1/9 Replicate of 3^6 Factorial (Continued).

Levels of ABCD:	0	0	0	1	1	1	2	2	2
Levels of CDEF:	0	1	2	0	1	2	0	1	2
54	122121	122122	122120	122220	122221	122222	122022	122020	122021
55	200102	200100	200101	200201	200202	200200	200000	200001	200002
56	200111	200112	200110	200210	200211	200212	200012	200010	200011
57	200120	200121	200122	200222	200220	200221	200021	200022	200020
58	201002	201000	201001	201101	201102	201100	201200	201201	201202
59	201011	201012	201010	201110	201111	201112	201212	201210	201211
60	201020	201021	201022	201122	201120	201121	201221	201222	201220
61	202202	202200	202201	202001	202002	202000	202100	202101	202102
62	202211	202212	202210	202010	202011	202012	202112	202110	202111
63	202220	202221	202222	202022	202020	202021	202121	202122	202120
64	210000	210001	210002	210102	210100	210101	210201	210202	210200
65	210012	210010	210011	210111	210112	210110	210210	210211	210212
66	210021	210022	210020	210120	210121	210122	210222	210220	210221
67	211200	211201	211202	211002	211000	211001	211101	211102	211100
68	211212	211210	211211	211011	211012	211010	211110	211111	211112
69	211221	211222	211221	211020	211021	211022	211122	211120	211121
70	212100	212101	212102	212202	212200	212201	212001	212002	212000
71	212112	212110	212111	212211	212212	212210	212010	212011	212012
72	212121	212122	212120	212220	212221	212222	212022	212020	212021
73	220201	220202	220200	220000	220001	220002	220102	220100	220101
74	220210	220211	220212	220012	220010	220011	220111	220112	220110
75	220222	220220	220221	220021	220022	220020	220120	220121	220122
76	221101	221102	221100	221200	221201	221202	221002	221000	221001
77	221110	221111	221112	221212	221210	221211	221011	221012	221010
78	221122	221120	221121	221221	221222	221220	221020	221021	221022
79	222001	222002	222000	222100	222101	222102	222202	222200	222201
80	222010	222011	222012	222112	222110	222111	222211	222212	222210
81	222022	222020	222021	222121	222122	222120	222220	222221	222222

Table 7-10. Sample Blocks for 1/8 Replicate of 2^6 Factorial.

Defining Equations

GHI: $X_7 + X_8 + X_9 = 0, 1, \text{MOD } 2$

JKL: $X_{10} + X_{11} + X_{12} = 0, 1, \text{MOD } 2$

GHKL: $X_7 + X_8 + X_{11} + X_{12} = 0, 1, \text{MOD } 2$

Levels of GHI:	0	0	0	0	1	1	1	1
Levels of JKL:	0	0	1	1	0	0	1	1
Levels of GHKL:	0	1	0	1	0	1	0	1
1	000000	000101	000100	000001	001000	001101	001100	001001
2	000011	000110	000111	000010	001011	001110	001111	001010
3	011101	011000	011001	011100	010101	010000	010001	010100
4	011110	011011	011010	011111	010110	010011	010010	010111
5	101101	101000	101001	101100	100101	100000	100001	100100
6	101110	101011	101010	101111	100110	100011	100010	100111
7	110000	110101	110100	110001	111000	111101	111100	111001
8	110011	110110	110111	110010	111011	111110	111111	111010

Table 7-11. Air Path Sensitivity Study Cases.

Variable	A	B	C	D	E	F	G	H	I	J	K	L
No. of levels	3	3	3	3	3	3	2	2	2	2	2	2

1/72 replicate of a $2^6 \times 3^6$ factorial

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
1	111311111311	25	133213111311	49	232211111311
2	111323111311	26	133222111311	50	232223111311
3	111332111311	27	133231111311	51	232232111311
4	112211111311	28	211212111311	52	233111111311
5	112223111311	29	211221111311	53	233123111311
6	112232111311	30	211233111311	54	233132111311
7	113111111311	31	212112111311	55	311113111311
8	113123111311	32	212121111311	56	311122111311
9	113132111311	33	212133111311	57	311131111311
10	121212111311	34	213312111311	58	312313111311
11	121221111311	35	213321111311	59	312322111311
12	121233111311	36	213333111311	60	312331111311
13	122112111311	37	221113111311	61	313213111311
14	122121111311	38	221122111311	62	313222111311
15	122133111311	39	221131111311	63	313231111311
16	123312111311	40	222313111311	64	321311111311
17	123321111311	41	222322111311	65	321323111311
18	123333111311	42	222331111311	66	321332111311
19	131113111311	43	223213111311	67	322211111311
20	131122111311	44	223222111311	68	322223111311
21	131131111311	45	223231111311	69	322232111311
22	132313111311	46	231311111311	70	323111111311
23	132322111311	47	231323111311	71	323123111311
24	132331111311	48	231332111311	72	323132111311

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
73	331212111311	103	132313111333	133	233111111333
74	331221111311	104	132322111333	134	233123111333
75	331233111311	105	132331111333	135	233132111333
76	332112111311	106	133213111333	136	311113111333
77	332121111311	107	133222111333	137	311122111333
78	332133111311	108	133231111333	138	311131111333
79	333312111311	109	211212111333	139	312313111333
80	333321111311	110	211221111333	140	312322111333
81	333333111311	111	211233111333	141	312331111333
82	111311111333	112	212112111333	142	313213111333
83	111323111333	113	212121111333	143	313222111333
84	111332111333	114	212133111333	144	313231111333
85	112211111333	115	213312111333	145	321311111333
86	112223111333	116	213321111333	146	321323111333
87	112232111333	117	213333111333	147	321332111333
88	113111111333	118	221113111333	148	322211111333
89	113123111333	119	221122111333	149	322223111333
90	113132111333	120	221131111333	150	322232111333
91	121212111333	121	222313111333	151	323111111333
92	121221111333	122	222322111333	152	323123111333
93	121233111333	123	222331111333	153	323132111333
94	122112111333	124	223213111333	154	331212111333
95	122121111333	125	223222111333	155	331221111333
96	122133111333	126	223231111333	156	331233111333
97	123312111333	127	231311111333	157	332112111333
98	123321111333	128	231323111333	158	332121111333
99	123333111333	129	231332111333	159	332133111333
100	131113111333	130	232211111333	160	333312111333
101	131122111333	131	232223111333	161	333321111333
102	131131111333	132	232232111333	162	333333111333

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
163	111311133113	193	212112133113	223	313213133113
164	111323133113	194	212121133113	224	313222133113
165	111332133113	195	212133133113	225	313231133113
166	112211133113	196	213312133113	226	321311133113
167	112223133113	197	213321133113	227	321323133113
168	112232133113	198	213333133113	228	321332133113
169	113111133113	199	221113133113	229	322211133113
170	113123133113	200	221122133113	230	322223133113
171	113132133113	201	221131133113	231	322232133113
172	121212133113	202	222313133113	232	323111133113
173	121221133113	203	222322133113	233	323123133113
174	121233133113	204	222331133113	234	323132133113
175	122112133113	205	223213133113	235	331212133113
176	122121133113	206	223222133113	236	331221133113
177	122133133113	207	223231133113	237	331233133113
178	123312133113	208	231311133113	238	332112133113
179	123321133113	209	231323133113	239	332121133113
180	123333133113	210	231332133113	240	332133133113
181	131113133113	211	232211133113	241	333312133113
182	131122133113	212	232223133113	242	333321133113
183	131131133113	213	232232133113	243	333333133113
184	132313133113	214	233111133113	244	111311133131
185	132322133113	215	233123133113	245	111323133131
186	132331133113	216	233132133113	246	111332133131
187	133213133113	217	311113133113	247	112211133131
188	133222133113	218	311122133113	248	112223133131
189	133231133113	219	311131133113	249	112232133131
190	211212133113	220	312313133113	250	113111133131
191	211221133113	221	312322133113	251	113123133131
192	211233133113	222	312331133113	252	113132133131

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
253	121212133131	283	222313133131	313	323111133131
254	121221133131	284	222322133131	314	323123133131
255	121233133131	285	222331133131	315	323132133131
256	122112133131	286	223213133131	316	331212133131
257	122121133131	287	223222133131	317	331221133131
258	122133133131	288	223231133131	318	331233133131
259	123312133131	289	231311133131	319	332112133131
260	123321133131	290	231323133131	320	332121133131
261	123333133131	291	231332133131	321	332133133131
262	131113133131	292	232211133131	322	333312133131
263	131122133131	293	232223133131	323	333321133131
264	131131133131	294	232232133131	324	333333113131
265	132313133131	295	233111133131	325	111311313113
266	132322133131	296	233123133131	326	111323313113
267	132331133131	297	233132133131	327	111332313113
268	133213133131	298	311113133131	328	112211313113
269	133222133131	299	311122133131	329	112223313113
270	133231133131	300	311131133131	330	112232313113
271	211212133131	301	312313133131	331	113132313113
272	211221133131	302	312322133131	332	113111313113
273	211233133131	303	312331133131	333	113132313113
274	212112133131	304	313213133131	334	121212313113
275	212121133131	305	313222133131	335	121221313113
276	212133133131	306	313231133131	336	121233313113
277	213312133131	307	321311133131	337	122112313113
278	213321133131	308	321323133131	338	122121313113
279	213333133131	309	321332133131	339	122133313113
280	221113133131	310	322211133131	340	123312313113
281	221122133131	311	322223133131	341	123321313113
282	221131133131	312	322232133131	342	123333313113

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
343	131113313113	373	232211313113	403	333312313113
344	131122313113	374	232223313113	404	333321313113
345	131131313113	375	232232313113	405	333333313113
346	132313313113	376	233111313113	406	111311313131
347	132322313113	377	233123313113	407	111323313131
348	132331313113	378	233132313113	408	111332313131
349	133213313113	379	311113313113	409	112211313131
350	133222313113	380	311122313113	410	112223313131
351	133231313113	381	311131313113	411	112232313131
352	211212313113	382	312313313113	412	113111313131
353	211221313113	383	312322313113	413	113123313131
354	211233313113	384	312331313113	414	113132313131
355	212112313113	385	313213313113	415	121212313131
356	212121313113	386	313222313113	416	121221313131
357	212133313113	387	313231313113	417	121233313131
358	213312313113	388	321311313113	418	122112313131
359	213321313113	389	321323313113	419	122121313131
360	213333313113	390	321332313113	420	122133313131
361	221113313113	391	322211313113	421	123312313131
362	221122313113	392	322223313113	422	123321313131
363	221131313113	393	322232313113	423	123333313131
364	222313313113	394	323111313113	424	131113313131
365	222322313113	395	323123313113	425	131122313131
366	222331313113	396	323132313113	426	131131313131
367	223213313113	397	331212313113	427	132313313131
368	223222313113	398	331221313113	428	132322313131
369	223231313113	399	331233313113	429	132331313131
370	231311313113	400	332112313113	430	133213313131
371	231323313113	401	332121313113	431	133222313131
372	231332313113	402	332133313113	432	133231313131

Table 7-11. Air Path sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
433	211212313131	463	312313313131	493	113111331311
434	211221313131	464	312322313131	494	113123331311
435	211233313131	465	312331313131	495	113132331311
436	212112313131	466	313213313131	496	121212331311
437	212121313131	467	313222313131	497	121221331311
438	212133313131	468	313231313131	498	121233331311
439	213312313131	469	321311313131	499	122112331311
440	213321313131	470	321323313131	500	122121331311
441	213333313131	471	321332313131	501	122133331311
442	221113313131	472	322211313131	502	123312331311
443	221122313131	473	322223313131	503	123321331311
444	221131313131	474	322232313131	504	123333331311
445	222313313131	475	323111313131	505	131113331311
446	222322313131	476	323123313131	506	131122331311
447	222331313131	477	323132313131	507	131131331311
448	223213313131	478	331212313131	508	132313331311
449	223222313131	479	331221313131	509	132322331311
450	223231313131	480	331233313131	510	132331331311
451	231311313131	481	332112313131	511	133213331311
452	231323313131	482	332121313131	512	133222331311
453	231332313131	483	332133313131	513	133231331311
454	232211313131	484	333312313131	514	211212331311
455	232223313131	485	333321313131	515	211221331311
456	232232313131	486	333333313131	516	211233331311
457	233111313131	487	111311331311	517	212112331311
458	233123313131	488	111323331311	518	212121331311
459	233132313131	489	111332331311	519	212133331311
460	311113313131	490	112211331311	520	213312331311
461	311122313131	491	112223331311	521	213321331311
462	311131313131	492	112232331311	522	213333331311

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
523	221113331311	553	322211331311	583	123312331333
524	221122331311	554	322223331311	584	123321331333
525	221131331311	555	322232331311	585	123333331333
526	222313331311	556	323111331311	586	131113331333
527	222322331311	557	323123331311	587	131122331333
528	222331331311	558	323132331311	588	131131331333
529	223213331311	559	331212331311	589	132313331333
530	223222331311	560	331221331311	590	132322331333
531	223231331311	561	331233331311	591	132331331333
532	231311331311	562	332112331311	592	133213331333
533	231323331311	563	332121331311	593	133222331333
534	231332331311	564	332133331311	594	133231331333
535	232211331311	565	333312331311	595	211212331333
536	232223331311	566	333321331311	596	211221331333
537	232232331311	567	333333331311	597	211233331333
538	233111331311	568	111311331333	598	212112331333
539	233123331311	569	111323331333	599	212121331333
540	233132331311	570	111332331333	600	212133331333
541	311113331311	571	112211331333	601	213312331333
542	311122331311	572	112223331333	602	213321331333
543	311131331311	573	112232331333	603	213333331333
544	312313331311	574	113111331333	604	221113331333
545	312322331311	575	113123331333	605	221122331333
546	312331331311	576	113132331333	606	221131331333
547	313213331311	577	121212331333	607	222313331333
548	313222331311	578	121221331333	608	222322331333
549	313231331311	579	121233331333	609	222331331333
550	321311331311	580	122112331333	610	223213331333
551	321323331311	581	122121331333	611	223222331333
552	321332331311	582	122133331333	612	223231331333

Table 7-11. Air Path Sensitivity Study Cases (Continued).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
613	231311331333	625	312313331333	637	323111331333
614	231323331333	626	312322331333	638	323123331333
615	231332331333	627	312331331333	639	323132331333
616	232211331333	628	313213331333	640	331212331333
617	232223331333	629	313222331333	641	331221331333
618	232232331333	630	313231331333	542	331233331333
619	233111331333	631	321311331333	643	332112331333
620	233123331333	632	321323331333	644	332121331333
621	233132331333	633	321332331333	645	332133331333
622	311113331333	634	322211331333	646	333312331333
623	311122331333	635	322223331333	647	333321331333
624	311131331333	636	322232331333	648	333333331333

The actual cases to be run for the sensitivity study design are found in the following manner. The interactions used in the contrast definition equation are used as defining equations to determine the sample blocks of the design. Tables 7-9 and 7-10 show the blocks for the design for each of the 3^6 and 2^6 factorials. Looking at Table 7-9, the two interactions ABCD and CDEF are the drivers for the defining equations. Since the design is a 1/9 replicate, nine blocks are shown. One block will be chosen randomly to be used as the actual test case definition. The six digit numbers in the table represent levels of each of the variables A through F. In Table 7-10, the six digit numbers correspond to levels of the variables G through L.

An example of the methodology used in generating the tables is as follows. In Table 7-9, row 17, 4th column (ABCD = 1, CDEF = 0) is the sequence 012112. Substituting this sequence into the defining equations at the top of the table yields:

$$X_1 + X_2 + X_3 + X_4 = 0 + 1 + 2 + 1 = 4 = 1 \text{ (MOD 3)}$$
$$X_3 + X_4 + X_5 + X_6 = 2 + 1 + 1 + 2 = 6 = 0 \text{ (MOD 3)}$$

Thus, the sequence 012112 should appear in the column for ABCD level equal to 1 and CDEF level equal to 0. The remainder of the table is filled using the defining equations in this manner.

Randomly selecting blocks from Tables 7-9 and 7-10 and then combining the blocks yields Table 7-11. Note that the numbers used in Table 7.11 are modified to allow easier coding of the input. A number one is equivalent to the number zero in the previous tables. Two is equivalent to one in Table 7-9, and three is equivalent to two in Table 7-9 and one in Table 7-10. The combined design has 648 tests as shown.

7.4.3 Water Path Experimental Design

The water path sensitivity study had a total of nine variables of which three had three levels and six had two levels. Thus, there was a potential of $3^3 \times 2^6$ or 1728 tests of the Systems Model. This experiment was also divided into two parts for the purpose of developing the design. The three variables with three levels were handled separately from the six variables with two levels. The design was a 1/12 replicate of the total factorial. This was defined by forming a 1/3 replicate of the 33 factorial and 1/4 replicate of the 26 factorial designs. The final sample size was 144 out of the 1728 possible samples.

Table 7-12 presents the design of a 1/3 replicate of the 33 factorial. Since the design was a (1/3)1 replicate, only one interaction was confounded with the identity. The defining interaction was ABC. Note that the main variables were confounded with two factor interactions.

Table 7-13 presents the design of a 1/4 replicate of the 26 factorial. Two interactions were confounded with the identity since the design was a (1/2)2 replicate. No main variables were confounded with two factor interactions in this design. The defining interactions were DEFG and FGHI.

Based on the above two designs, the parameters of the model were assigned to the variables in the design as shown in Table 7-14. Interactions were evaluated as follows: AF, BF, CE, DF, CH, EF, EI, FH, and HI. All other interactions were assumed to have insignificant effects in the Systems Model or are confounded with effects of interest.

Sample blocks for the two designs are shown in Tables 7-15 and 7-16. Table 7-17 shows the actual test cases based on a combination of random blocks from Tables 7-15 and 7-16. Final tests numbered 144 out of the 1728 possible tests.

7.5. RESULTS AND DISCUSSION

This section discusses the methodology for evaluation of the test runs and the results obtained. Many runs where made prior to the sensitivity study runs. These tests were necessary to define ranges for the input variables which would yield results that could be evaluated. In many cases, realistic values for some variables gave zero outputs which tended to degrade the sensitivity study information. This aspect of the study will be discussed further in the following sections. Actual data from the Systems Model runs is shown in the Appendix of this report.

Table 7-12. 1/3 Replicate of a 3^3 Factorial Design.

Defining contrast $I = ABC = [ABC]^2$

Aliases or confounding scheme

$$A = AB^2C^2 = BC$$

$$B = AB^2C = AC$$

$$C = ABC^2 = AB$$

$$AB^2 = AC^2 = BC^2$$

Table 7-13. 1/4 Replicate of a 2^6 Factorial Design.

Defining contrast I = DEFG = FGHI = DEHI

Aliases or confounding scheme

D = EFG = DFGHI = EHI
E = DFG = EFGHI = DHI
F = DEG = GHI = DEFHI
G = DEF = FHI = DEGHI
H = DEFGH = FGI = DEI
I = DEFGI = FGH = DEH
DE = FG = DEFGHI = HI
DF = EG = DGHI = EFHI
DG = EF = DFHI = EGHI
DH = EFGH = DFGI = EI
DI = EFGI = DFGH = EH
FH = DEGH = GI = DEFI
FI = DEGI = GH = DEFH
DFH = EGH = DGI = EFI
DFI = EGI = DGH = EFH

Table 7-14. Water Path Sensitivity Study Variable Definition.

Variable	Variable Name
A	Weather
B	Layers in soil column
C	Equilibrium constant
D	Nuclide quantity
E	Water travel time
F	Retardation factor
G	Aquifer dispersion
H	Nuclide solubility
I	Water body flow

Table 7-15. Sample Blocks for 1/3 Replicate of 3^3 Factorial.

Defining equation

ABC: $X_1 + X_2 + X_3 = 0, 1, 2, \text{Mod } 3$

Levels of ABC:	0	1	2
1	000	001	002
2	012	010	020
3	102	100	200
4	120	022	122
5	021	202	212
6	201	220	221
7	210	211	011
8	111	121	101
9	222	112	110

Table 7-16. Sample Blocks for 1/4 Replicate of 2^6 Factorial.

Defining equations

DEFG: $X_4 + X_5 + X_6 + X_7 = 0, 1, \text{MOD } 2$

FGHI: $X_6 + X_7 + X_8 + X_9 = 0, 1, \text{MOD } 2$

Levels of DEFG:	0	0	1	1
Levels of FGHI:	0	1	0	1
1	000000	000001	000101	000100
2	000011	000010	000110	000111
3	001100	001101	001001	001000
4	001111	001110	001010	001011
5	010101	010100	010000	010001
6	010110	010111	010011	010010
7	011001	011000	011100	011101
8	011010	011011	011111	011110
9	100101	100100	100000	100001
10	100110	100111	100011	100010
11	101001	101000	101100	101101
12	101010	101011	101111	101110
13	110000	110001	110101	110100
14	110011	110010	110110	110111
15	111100	111101	111001	111000
16	111111	111110	111010	111011

Table 7-17. Water Path Sensitivity Study Cases.

Variable	A	B	C	D	E	F	G	H	I
No. of levels	3	3	3	2	2	2	2	2	2

1/12 replicate of a $2^6 \times 3^3$ factorial

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
1	113111113	25	122113313	49	233131333
2	131111113	26	212113313	50	323131333
3	311111113	27	221113313	51	332131333
4	233111113	28	113113331	52	122131333
5	323111113	29	131113331	53	212131333
6	332111113	30	311113331	54	221131333
7	122111113	31	233113331	55	113133111
8	212111113	32	323113331	56	131133111
9	221111113	33	332113331	57	311133111
10	113111131	34	122113331	58	233133111
11	131111131	35	212113331	59	323133111
12	311111131	36	221113331	60	332133111
13	233111131	37	113131311	61	122133111
14	323111131	38	131131311	62	212133111
15	332111131	39	311131311	63	221133111
16	122111131	40	233131311	64	113133133
17	212111131	41	323131311	65	131133133
18	221111131	42	332131311	66	311133133
19	113113313	43	122131311	67	233133133
20	131113313	44	212131311	68	323133133
21	311113313	45	221131311	69	332133133
22	233113313	46	113131333	70	122133133
23	323113313	47	131131333	71	212133133
24	332113313	48	311131333	72	221133133

Table 7-17. Water Path Sensitivity Study Cases (Continuted).

Case No.	Variable Level	Case No.	Variable Level	Case No.	Variable Level
73	113311311	97	122313111	121	233331131
74	131311311	98	212313111	122	323331131
75	311311311	99	221313111	123	332331131
76	233311311	100	113313133	124	122331131
77	323311311	101	131313133	125	313331131
78	332311311	102	311313133	126	221331131
79	122311311	103	233313133	127	113333313
80	212311311	104	323313133	128	131333313
81	221311311	105	332313133	129	311333313
82	113311333	106	122313133	130	233333313
83	131311333	107	212313133	131	323333313
84	311311333	108	221313133	132	332333313
85	233311333	109	113331113	133	122333313
86	323311333	110	131331113	134	212333313
87	332311333	111	311331113	135	221333313
88	122311333	112	233331113	136	113333331
89	212311333	113	323331113	137	131333331
90	221311333	114	332331113	138	311333331
91	113313111	115	122331113	139	233333331
92	131313111	116	212331113	140	323333331
93	311313111	117	221331113	141	332333331
94	233313111	118	113331131	142	122333331
95	323313111	119	131331131	143	212333331
96	332313111	120	311331131	144	221333331

7.5.1 Evaluation Approach

A standard Analysis of Variance approach was used for the evaluation of fractional factorial designs. In the air and water path sensitivity studies, variables which were felt to have significant effects in the Systems Model were evaluated in the analysis. The model for the two studies are random rather than fixed models due to the large ranges that exist for most parameters. The Expected Mean Squares for the variables were derived based on the above two statements. The error terms in the analysis or variance were composed of all interactions which were felt to be insignificant.

7.5.2 Air Path Results

Table 7-18 presents the model assumptions for the air path analysis of variance. Thirty variables and interactions were chosen to be evaluated as shown. Based on this selection, the error term was defined as listed in the table. Using a random model analysis format, the E(MS) or Expected Mean Squares column of the table was determined. These E(MS)'s are important in determining what the test statistics should be for each variable. Variables in Table 7-18 are defined in Table 7-8.

The equations in Table 7-19 are the Sum of Squares (SS) computational formulas for the analysis. Note that variable I is equivalent to variable J due to the design. Thus, a SS_J does not exist in Table 7-19 due to the appearance of SS_I.

The results of the Systems Model runs for the air path sensitivity study are shown in Table 7-20. This table is presented in a standard analysis of variance format. Variables of interest are listed along with their corresponding degrees of freedom (d.f.). The sum of the degrees of freedom of the variables and error equals the total degrees of freedom. The column labeled SS is the sum of squares associated with each variable based on the formulas in Table 7-20. The MS column is the mean square for each variables and is found by dividing SS by d.f. The F_{TEST} column is a ratio of mean squares and is used to indicate if the effect of the variable is significant. The F=.1 column is the value which indicates if F_{TEST} is significant. These values come from a table of the F distribution. The F' columns are tests using a pooled error estimate found by combining all insignificant interactions with the old error estimate.

Table 7-18. Analysis of Variance for Air Path Sensitivity Study.

Variables	d.f.	E(MS)
A	2	$\sigma^2 + 72\,\sigma^2_{AC} + 72\,\sigma^2_{AD} + 72\,\sigma^2_{AE} + 72\,\sigma^2_{AF} + 108\,\sigma^2_{AG} + 108\,\sigma^2_{AK} + 108\,\sigma^2_{AL} + 216\,\sigma^2_{A}$
B	2	$\sigma^2 + 216\,\sigma^2_{B}$
C	2	$\sigma^2 + 72\,\sigma^2_{AC} + 72\,\sigma^2_{CE} + 72\,\sigma^2_{CF} + 108\,\sigma^2_{CG} + 108\,\sigma^2_{CH} + 108\,\sigma^2_{CL} + 216\,\sigma^2_{C}$
D	2	$\sigma^2 + 72\,\sigma^2_{AD} + 216\,\sigma^2_{D}$
E	2	$\sigma^2 + 72\,\sigma^2_{AE} + 72\,\sigma^2_{CE} + 72\,\sigma^2_{EF} + 108\,\sigma^2_{EG} + 108\,\sigma^2_{EK} + 216\,\sigma^2_{E}$
F	2	$\sigma^2 + 72\,\sigma^2_{AF} + 72\,\sigma^2_{CF} + 72\,\sigma^2_{EF} + 108\,\sigma^2_{FG} + 108\,\sigma^2_{FK} + 216\,\sigma^2_{F}$
G	1	$\sigma^2 + 108\,\sigma^2_{AG} + 108\,\sigma^2_{CG} + 108\,\sigma^2_{EG} + 108\,\sigma^2_{FG} + 162\,\sigma^2_{GK} + 162\,\sigma^2_{GL} + 324\,\sigma^2_{G}$
H	1	$\sigma^2 + 108\,\sigma^2_{CH} + 324\,\sigma^2_{H}$
I/J	1	$\sigma^2 + 324\,\sigma^2_{I}$
K	1	$\sigma^2 + 108\,\sigma^2_{AK} + 108\,\sigma^2_{EK} + 108\,\sigma^2_{FK} + 162\,\sigma^2_{GK} + 324\,\sigma^2_{K}$
L	1	$\sigma^2 + 108\,\sigma^2_{AL} + 108\,\sigma^2_{CL} + 162\,\sigma^2_{GL} + 324\,\sigma^2_{L}$
$AC + AC^2$	4	$\sigma^2 + 72\,\sigma^2_{AC}$
$AD + AD^2$	4	$\sigma^2 + 72\,\sigma^2_{AD}$
$AE + AE^2$	4	$\sigma^2 + 72\,\sigma^2_{AE}$
$AF + AF^2$	4	$\sigma^2 + 72\,\sigma^2_{AF}$
AG	2	$\sigma^2 + 108\,\sigma^2_{AG}$
AK	2	$\sigma^2 + 108\,\sigma^2_{AK}$
AL	2	$\sigma^2 + 108\,\sigma^2_{AL}$
$CD + CE^2$	4	$\sigma^2 + 72\,\sigma^2_{CE}$
$CF + CF^2$	4	$\sigma^2 + 72\,\sigma^2_{CF}$
CG	2	$\sigma^2 + 108\,\sigma^2_{CG}$
CH	2	$\sigma^2 + 108\,\sigma^2_{CH}$
CL	2	$\sigma^2 + 108\,\sigma^2_{CL}$
$EF + EF^2$	4	$\sigma^2 + 72\,\sigma^2_{EF}$
EG	2	$\sigma^2 + 108\,\sigma^2_{EG}$
EK	2	$\sigma^2 + 108\,\sigma^2_{EK}$
FG	2	$\sigma^2 + 108\,\sigma^2_{FG}$
FK	2	$\sigma^2 + 108\,\sigma^2_{FK}$
GK	1	$\sigma^2 + 162\,\sigma^2_{GK}$
GL	1	$\sigma^2 + 162\,\sigma^2_{GL}$
ERROR	580	σ^2

Table 7-18. Analysis of Variance for Air Path Sensitivity Study. (Continued)

Error term is composed of the following interactions which are assumed to be zero

ERROR = AB^2 , AH , AI , BC^2 , BD^2 , BE , BF , BG , BH ,
BI , BK , BL , CD^2 , CI , CK , DE^2 , DF^2 , DG ,
DH , DI , DK , DL , EH , EI , EL , FH , FI ,
FL , AB^2G, AB^2H , AB^2I, AB^2K, AB^2L, ACE ,
ACE^2, AC^2E, AC^2E^2, ACF , ACF^2, AC^2F, AC^2F^2,
ACG , AC^2G, ACH , AC^2H, ACI , AC^2I, ACK ,
AC^2K, ACL , AC^2L , ADE^2, AD^2E, ADF^2, AD^2F ,
ADG , AD^2G, ADH , AD^2H, ADI , AD^2I, ADK ,
AD^2K, ADL , AD^2L , AEG , AE^2G, AEH , AE^2H ,
AEI , AE^2I, AEK , AE^2K, AEL , AE^2L, AFG ,
AF^2G, AFH , AF^2H , AFI , AF^2I, AFK , AF^2K ,
AFL , AF^2L, AGK , AGL , BC^2G, BC^2H, BC^2I ,
BC^2K, BC^2L, BD^2G , BD^2H, BD^2I, BD^2K, BD^2L ,
BEG , BEH , BEI , BEK , BEL , BFG , BFH ,
BFI , BFK , BFL , BGK , BGL , CD^2G, CD^2H ,
CD^2I, CD^2K, CD^2L , CEG , CE^2G, CEH , CE^2H ,
CEI , CE^2I, CEK , CE^2K, CEL , CE^2L, CFG ,
CF^2G, CFH , CF^2H , CFI , CF^2I, CFK , CF^2K ,
CFL , CF^2L, CGK , CGL , DE^2G, DE^2H, DE^2I ,
DE^2K, DE^2L, DF^2G , DF^2H, DF^2I, DF^2K, DF^2L ,
DGK , DGL , EFG , EF^2G, EFH , EF^2H, EFI ,
EF^2I, EFK, EF^2K , EFL , EF^2L, EGK , EGL ,
FGK , FGL, AB^2GK, AB^2GL, ACEG, ACE^2G, AC^2EG,
AC^2E^2G , ACEH , ACE^2H , AC^2EH , AC^2E^2H, ACEI , ACE^2I ,
AC^2EI , AC^2E^2I , ACEK , ACE^2K , AC^2EK , AC^2E^2K , ACEL ,
ACE^2L , AC^2EL , AC^2E^2L , ACFG , ACF^2G , AC^2FG , AC^2F^2G,
ACFH , ADF^2H , AC^2FH , AC^2F^2H, ACFI , ACF^2I , AC^2FI ,
AC^2F^2I , ACFK , ACF^2K , AC^2FK , AC^2F^2K, ACFL , ACF^2L ,
AC^2FL , AC^2F^2L , ACGK , AC^2GK , ACGL , AC^2GL , ADE^2G ,
AD^2EG , ADE^2H , AD^2EH , ADE^2I , AD^2EI , ADE^2K , AD^2EK ,
ADE^2L , AD^2EL , ADF^2G , AD^2FG , ADF^2H , AD^2FH , ADF^2I ,
AD^2FI , ADF^2K , AD^2FK , ADF^2L , AD^2FL , ADGK , AD^2GK ,
ADGL , AD^2GL , AEGK , AE^2GK , AEGL , AE^2GL , AFGK ,
AF^2GK , AFGL , AF^2GL , BC^2GK , BC^2GL , BD^2GK , BD^2GL ,
BEGK , BEGL , BFGK , BFGL , CD^2GK , CD^2GL , CEGK ,
CE^2GK , CEGL , CE^2GL , CFGK , CF^2GK , CFGL , CF^2GL ,
DE^2GK , DE^2GL , DF^2GK , DF^2GL , EFGK , EF^2GK , EFGL ,
EF^2GL , ACEGK , ACE^2GK , AC^2EGK, AC^2E^2GK, ACEGL ,
ACE^2GL , AC^2EGL , AC^2E^2GL, ACFGK , ACF^2GK , AC^2FGK ,
AC^2F^2GK, ACFGL , ACF^2GL , AC^2FGL, AC^2F^2GL, ADE^2GK ,
AD^2EGK , ADE^2GL , AD^2EGL , ADF^2GK, AD^2FGK , ADF^2GL ,
AD^2FGL ,

Table 7-19. Computational Formulas for Air Path ANOVA.

$$SS_A = \sum_{a}^{3} (Xa...........)^2/216 - (X............)^2/648$$

$$SS_B = \sum_{b}^{3} (X.b..........)^2/216 - (X............)^2/648$$

$$SS_C = \sum_{c}^{3} (X..c.........)^2/216 - (X............)^2/648$$

$$SS_D = \sum_{d}^{3} (X...d........)^2/216 - (X............)^2/648$$

$$SS_E = \sum_{e}^{3} (X....e.......)^2/216 - (X............)^2/648$$

$$SS_F = \sum_{f}^{3} (X.....f......)^2/216 - (X............)^2/648$$

$$SS_G = \sum_{g}^{2} (X......g.....)^2/324 - (X............)^2/648$$

$$SS_H = \sum_{h}^{2} (X.......h....)^2/324 - (X............)^2/648$$

$$SS_I = \sum_{i}^{2} (X........i...)^2/324 - (X............)^2/648$$

$$SS_K = \sum_{k}^{2} (X..........k.)^2/324 - (X............)^2/648$$

$$SS_L = \sum_{l}^{2} (X...........l)^2/324 - (X............)^2/648$$

$$SS_{AC} = \sum\sum_{ac}^{33}(Xa.c.........)^2/72 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{c}^{3}(X..c.........)^2/216 + (X............)^2/648$$

$$SS_{AD} = \sum\sum_{ad}^{33}(Xa..d........)^2/72 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{d}^{3}(X...d........)^2/216 + (X............)^2/648$$

$$SS_{AE} = \sum\sum_{ae}^{33}(Xa...e.......)^2/72 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{3}^{3}(X....e.......)^2/216 + (X............)^2/648$$

$$SS_{AF} = \sum\sum_{af}^{33}(Xa....f......)^2/72 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{f}^{3}(X.....f......)^2/216 + (X............)^2/648$$

$$SS_{AG} = \sum\sum_{ag}^{32}(Xa.....g.....)^2/108 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{g}^{2}(X......g.....)^2/324 + (X............)^2/648$$

$$SS_{AK} = \sum\sum_{ak}^{32}(Xa.........k.)^2/108 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{k}^{2}(X..........k.)^2/324 + (X............)^2/648$$

$$SS_{AL} = \sum\sum_{al}^{32}(Xa..........l)^2/108 - \sum_{a}^{3}(Xa...........)^2/216 - \sum_{l}^{2}(X...........l)^2/324 + (X............)^2/648$$

Table 7-19. Computational Formulas for Air Path ANOVA. (Continued)

$$SS_{CE} = \sum\sum_{ce}^{33}(X_{..c.e.......})^2/72 - \sum_{c}^{3}(X_{..c.........})^2/216 - \sum_{e}^{3}(X_{....e.......})^2/216 + (X_{............})^2/648$$

$$SS_{CF} = \sum\sum_{cf}^{33}(X_{..c..f......})^2/72 - \sum_{c}^{3}(X_{..c.........})^2/216 - \sum_{f}^{3}(X_{.....f......})^2/216 + (X_{............})^2/648$$

$$SS_{CG} = \sum\sum_{cg}^{32}(X_{..c...g.....})^2/108 - \sum_{c}^{3}(X_{..c.........})^2/216 - \sum_{g}^{2}(X_{......g.....})^2/324 + (X_{............})^2/648$$

$$SS_{CH} = \sum\sum_{ch}^{32}(X_{..c....h....})^2/108 - \sum_{c}^{3}(X_{..c.........})^2/216 - \sum_{h}^{2}(X_{.......h....})^2/324 + (X_{............})^2/648$$

$$SS_{CL} = \sum\sum_{cl}^{32}(X_{..c........l})^2/108 - \sum_{c}^{3}(X_{..c.........})^2/216 - \sum_{l}^{2}(X_{...........l})^2/324 + (X_{............})^2/648$$

$$SS_{EF} = \sum\sum_{ef}^{33}(X_{....ef......})^2/72 - \sum_{e}^{3}(X_{....e.......})^2/216 - \sum_{f}^{3}(X_{.....f......})^2/216 + (X_{............})^2/648$$

$$SS_{EG} = \sum\sum_{eg}^{32}(X_{....e.g.....})^2/108 - \sum_{e}^{3}(X_{....e.......})^2/216 - \sum_{g}^{2}(X_{......g.....})^2/324 + (X_{............})^2/648$$

$$SS_{EK} = \sum\sum_{ek}^{32}(X_{....e.....k.})^2/108 - \sum_{e}^{3}(X_{....e.......})^2/216 - \sum_{k}^{2}(X_{..........k.})^2/324 + (X_{............})^2/648$$

$$SS_{FG} = \sum\sum_{fg}^{32}(X_{.....fg.....})^2/108 - \sum_{f}^{3}(X_{.....f......})^2/216 - \sum_{g}^{2}(X_{......g.....})^2/324 + (X_{............})^2/648$$

$$SS_{FK} = \sum\sum_{fk}^{32}(X_{.....f....k.})^2/108 - \sum_{f}^{3}(X_{.....f......})^2/216 - \sum_{k}^{2}(X_{..........k.})^2/324 + (X_{............})^2/648$$

$$SS_{GK} = \sum\sum_{gk}^{22}(X_{......g...k.})^2/162 - \sum_{g}^{2}(X_{......g.....})^2/324 - \sum_{k}^{2}(X_{..........k.})^2/324 + (X_{............})^2/648$$

$$SS_{GL} = \sum\sum_{gl}^{22}(X_{......g....l})^2/162 - \sum_{g}^{2}(X_{......g.....})^2/324 - \sum_{l}^{2}(X_{...........l})^2/324 + (X_{............})^2/648$$

$$SS_{TOTAL} = \sum_{all} X_{abcdefgnijkl}^2 - (X_{............})^2/648$$

$$SS_{ERROR} = SS_{TOTAL} - \text{All other SS}$$

Table 7-20. Analysis of Variance Results for Air Path Sensitivity Study.

Variable	d.f.	SS	MS	F_{TEST}	$F_{\alpha=.1}$	F'_{TEST}	$F'_{\alpha=.1}$
A	2	2.810E+12	1.405E+12	1.02	5.15		
B	2	6.010E+13	3.005E+13	18.46*	2.30		
C	2	5.060E+09	2.530E+09	966.00*	5.13	0.0016	2.30
D	2	1.154E+10	5.770E+09	6.13**	4.32	0.0037	2.30
E	2	1.214E+12	6.070E+11	0.84	3.78		
F	2	3.403E+13	1.702E+13	0.69	5.34		
G	1	3.912E+13	3.912E+13	0.52	49.50		
H	1	3.352E+13	3.352E+13	22600.0*	8.53	21.65*	2.71
I/J	1	3.468E+13	3.468E+13	21.30*	2.71		
K	1	3.883E+13	3.883E+13	0.79	8.53		
L	1	3.601E+13	3.601E+13	1.09	39.86		
AC	4	2.304E+09	5.760E+08	0.00035	1.94		
AD	4	3.764E+09	9.410E+08	0.00058	1.94		
AE	4	2.617E+13	6.542E+12	4.02*	1.94		
AF	4	2.510E+12	6.275E+11	0.39	1.94		
AG	2	2.573E+12	1.286E+12	0.79	2.30		
AK	2	2.406E+12	1.203E+12	0.74	2.30		
AL	2	2.611E+12	1.306E+12	0.80	2.30		
CE	4	5.076E+09	1.269E+09	0.000078	1.94		
CF	4	4.500E+09	1.125E+09	0.000069	1.94		
CG	2	4.036E+09	2.018E+09	0.00012	2.30		
CH	2	2.972E+09	1.486E+09	0.000091	2.30		
CL	2	3.906E+09	1.953E+09	0.00012	2.30		
EF	4	3.464E+12	8.660E+11	0.53	1.94		
EG	2	1.107E+12	5.535E+11	0.34	2.30		
EK	2	9.544E+11	4.772E+11	0.29	2.30		
FG	2	3.291E+13	1.646E+13	10.11*	2.30		
FK	2	3.240E+13	1.620E+13	9.95*	2.30		
GK	1	3.761E+13	3.761E+13	23.10*	2.71		
GL	1	3.479E+13	3.479E+13	21.37*	2.71		
ERROR	580	9.441E+14	1.628E+12				
TOTAL	647	1.404E+15					

* Significant at $\alpha=.1$ level and at $\alpha=.05$ level

** Significant at $\alpha=.1$ level but not at $\alpha=.05$ level

The information in Table 7-18 is used to generate the F_{TEST} column in Table 7-20. Ratios of mean squares are determined by the variance effects shown in the E(MS) or expected mean square column of Table 7-18. In all cases where the variance of the effect is summed with the error variance, the ratio is simply the MS of the efect divided by the MS for error. This is true for the following effects: B, I/J, and all interactions. Other ratios all found by finding an E(MS) which has all the variance terms equal with the E(MS) of the variable of interest except for the variance of the effect of interest. If no candidates exist for this ratio, then combinations of the E(MS)'s are found which can produce this result. The degrees or freedom for these composite ratios is found using an approximation developed by Satterthwaite. For example, the F_{TEST} for variable L is found by

$$(MS_{error} + MS_{error} + MS_{L})/(MS_{AL} + MS_{CL} + MS_{GL}).$$

Based on the above derivations, variables B, C, D, H, I/J, AE, FG, FK, GK, and GL were found to have significant effects at an F = .1 level. Retesting C, D, and H based on a pooled error variance estimate resulted in different conclusions for variables C and D. Thus, it is concluded that the C and D effects are not really significant in this model.

7.5.3 Water Path Results

Table 7-21 presents the water path sensitivity study model assumptions for an analysis of variance. Eighteen variables and interactions were chosen for evaluation as indicated in the table. The error term was composed of the terms listed in the table, all of which were assumed to have no impact on the Systems Model. The E(MS)'s for the variables are shown. Variables are defined in Table 7-14.

Table 7-22 presents the computational formulas for the variable sum of squares. The results of the analysis are shown in Table 7-23. The effects of significance were D, CE, EH, EI, and HI with CE being less significant than the others. Interpretations of these results are provided in the following section.

Table 7-21. Analysis of Variance for Water Path Sensitivity Study.

Variable	d.f.	E[MS]
A	2	$\sigma^2 + 24\sigma_{AF}^2 + 48\sigma_A^2$
B	2	$\sigma^2 + 24\sigma_{BF}^2 + 48\sigma_B^2$
C	2	$\sigma^2 + 24\sigma_{CE}^2 + 24\sigma_{CF}^2 + 24\sigma_{CH}^2 + 48\sigma_C^2$
D	1	$\sigma^2 + 72\sigma_D^2$
E	1	$\sigma^2 + 24\sigma_{CE}^2 + 36\sigma_{EH}^2 + 36\sigma_{EI}^2 + 72\sigma_E^2$
F	1	$\sigma^2 + 24\sigma_{AF}^2 + 24\sigma_{BF}^2 + 24\sigma_{CF}^2 + 36\sigma_{FH}^2 + 72\sigma_F^2$
G	1	$\sigma^2 + 72\sigma_G^2$
H	1	$\sigma^2 + 24\sigma_{CH}^2 + 36\sigma_{EH}^2 + 36\sigma_{FH}^2 + 36\sigma_{HI}^2 + 72\sigma_H^2$
I	1	$\sigma^2 + 36\sigma_{EI}^2 + 36\sigma_{HI}^2 + 72\sigma_I^2$
AF	2	$\sigma^2 + 24\sigma_{AF}^2$
BF	2	$\sigma^2 + 24\sigma_{BF}^2$
CE	2	$\sigma^2 + 24\sigma_{CE}^2$
CF	2	$\sigma^2 + 24\sigma_{CF}^2$
CH	2	$\sigma^2 + 24\sigma_{CH}^2$
EH	1	$\sigma^2 + 36\sigma_{EH}^2$
EI	1	$\sigma^2 + 36\sigma_{EI}^2$
FH	1	$\sigma^2 + 36\sigma_{FH}^2$
HI	1	$\sigma^2 + 36\sigma_{HI}^2$
Error	117	σ^2

Error term is composed of following interactions which are assumed to be zero.

Error = AB^2, AD, AE, AG, AH, AI, BD, BE, BG, BH, BI,
CD, CG, CI, DF, DG, FI, AB^2D, AB^2E, AB^2F, AB^2G,
AB^2H, AB^2I, ADF, ADG, AEH, AEI, AFH, AFI, AHI,
BDF, BDG, BEH, BEI, BFH, BFI, BHI, CDF, CDG, CEH,
CEI, CFH, CFI, CHI, DFH, DFI, AB^2DF, AB^2DG, AB^2EH,
AB^2EI, AB^2FH, AB^2FI, AB^2HI, ADFH, ADFI, BDFH, BDFI,
CDFH, CDFI, AB^2DFH, AB^2DFI

Table 7-22. Computational Formulas for Water Path ANOVA.

$$SS_A = \sum_{a}^{3}(Xa........)^2/48 - (X.........)^2/144$$

$$SS_B = \sum_{b}^{3}(X.b.......)^2/48 - (X.........)^2/144$$

$$SS_C = \sum_{c}^{3}(X..c......)^2/48 - (X.........)^2/144$$

$$SS_D = \sum_{d}^{2}(X...d.....)^2/72 - (X.........)^2/144$$

$$SS_E = \sum_{e}^{2}(X....e....)^2/72 - (X.........)^2/144$$

$$SS_F = \sum_{f}^{2}(X.....f...)^2/72 - (X.........)^2/144$$

$$SS_G = \sum_{g}^{2}(X......g..)^2/72 - (X.........)^2/144$$

$$SS_H = \sum_{h}^{2}(X.......h.)^2/72 - (X.........)^2/144$$

$$SS_I = \sum_{i}^{2}(X........i)^2/72 - (X.........)^2/144$$

$$SS_{AF} = \sum_{a}^{3}\sum_{f}^{2}(Xa....f...)^2/24 - \sum_{a}^{3}(Xa........)^2/48 - \sum_{f}^{2}(X.....f...)^2/72 + (X.........)^2/144$$

$$SS_{BF} = \sum_{b}^{3}\sum_{f}^{2}(X.b...f...)^2/24 - \sum_{b}^{3}(X.b.......)^2/48 - \sum_{f}^{2}(X.....f...)^2/72 + (X.........)^2/144$$

$$SS_{CE} = \sum_{c}^{3}\sum_{e}^{2}(X..c.e....)^2/24 - \sum_{c}^{3}(X..c......)^2/48 - \sum_{e}^{2}(X....e....)^2/72 + (X.........)^2/144$$

Table 7-22 Computational Formulas for Water Path ANOVA. (Continued)

$$SS_{CF} = \sum_{c}^{3}\sum_{f}^{2}(X..c..f...)^2/24 - \sum_{c}^{3}(X..c......)^2/48 - \sum_{f}^{2}(X.....f...)^2/72 + (X.........)^2/144$$

$$SS_{CH} = \sum_{c}^{3}\sum_{h}^{2}(X..c....h.)^2/24 - \sum_{c}^{3}(X..c......)^2/48 - \sum_{h}^{2}(X.......h.)^2/72 + (X.........)^2/144$$

$$SS_{EH} = \sum_{e}^{2}\sum_{h}^{2}(X....e..h.)^2/36 - \sum_{e}^{2}(X....e....)^2/72 - \sum_{h}^{2}(x.......h.)^2/72 + (X.........)^2/144$$

$$SS_{EI} = \sum_{e}^{2}\sum_{i}^{2}(X....e...i)^2/36 - \sum_{e}^{2}(X....e....)^2/72 - \sum_{i}^{2}(X........i)^2/72 + (X.........)^2/144$$

$$SS_{FH} = \sum_{f}^{2}\sum_{h}^{2}(X.....f.h.)^2/36 - \sum_{f}^{2}(X.....f...)^2/72 - \sum_{h}^{2}(X.......h.)^2/72 + (X.........)^2/144$$

$$SS_{HI} = \sum_{h}^{2}\sum_{i}^{2}(X.......hi)^2/36 - \sum_{h}^{2}(X.......h.)^2/72 - \sum_{i}^{2}(X........i)^2/72 + (X.........)^2 144$$

$$SS_{Total} = \sum_{all} Xabcdefghi^2 - (X.........)^2/144$$

$$SS_{Error} = SS_{Total} - \text{All other SS}$$

Table 7-23. Analysis of Variance Results for Water Path Sensitivity Study.

Variable	d.f.	SS	MS	F_{TEST}	$F_{\alpha=.1}$	F'_{TEST}	$F'_{\alpha=.1}$
A	2	2.854E+07	1.427E+07	3.34	9.00	1.89	2.35
B	2	1.399E+07	6.995E+06	5.20	9.00	0.93	2.35
C	2	1.139E+08	5.695E+07	1.81	3.62		
D	1	3.596E+08	3.596E+08	46.84*	2.75		
E	1	9.001E+07	9.001E+07	0.23	8.53		
F	1	5.044E+06	5.044E+06	2.83	3.16	0.67	2.75
G	1	4.530E+04	4.530E+04	0.0059	2.75		
H	1	8.498E+07	8.498E+07	0.24	9.00		
I	1	3.520E+08	3.520E+08	2.06	8.53		
AF	2	8.544E+06	4.272E+06	0.56	2.35		
BF	2	2.690E+06	1.345E+06	0.18	2.35		
CE	2	3.677E+07	1.838E+07	2.39**	2.35		
CF	2	8.540E+06	4.270E+06	0.56	2.35		
CH	2	3.453E+07	1.726E+07	2.25	2.35		
EH	1	3.455E+08	3.455E+08	45.00*	2.75		
EI	1	8.648E+07	8.648E+07	11.26*	2.75		
FH	1	4.351E+04	4.351E+04	0.0057	2.75		
HI	1	8.845E+07	8.845E+07	11.52*	2.75		
ERROR	117	8.983E+08	7.678E+06				
TOTAL	143	2.558E+09					

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*Significant at $\alpha=.1$ level and at $\alpha=.05$ level

**Significant at $\alpha=.1$ level but not at $\alpha=.05$ level

7.6 CONCLUSIONS

Valuable information dealing with the Systems Model was obtained as a result of performing the sensitivity studies. Pre-study test runs and the study results provided insight into the operation of the code and the importance of the input variables. Code run time was decreased without significantly changing the calculated doses. No major changes were found to be necessary in the Systems Model in order to yield an effective analytical tool. The significance of the input variables was determined with some surprises and is discussed in detail in the following text.

A key finding in the pre-study test run was that input variables must have exaggerated values in many cases in order for the model to compute a non-zero dose. An initial water path study had many zero results. Inputs were modified in order to force non-zero answers. When analytical results were compared for the two studies, no significant changes were made in the conclusions. Thus, the large number of zeros in the air path study shown in the Appendix is felt to have little impact on the conclusions.

Certain variables were found to act almost like switches in the Systems Model. Many of these variables were not significant in the sensitivity studies but had to be carefully controlled in order to get non-zero results. Specifically, weather, aquifer sorption equilibrium constant, water travel time, retardation factor, and nuclide solubility (variables A, C, E, F, and H in water path study) acted as switches in the water path sensitivity study. Weather, nuclide solubility, site wind resistance, and retardation factor (variables A, H, K, and L in air path study) also acted as switches in the air path sensitivity runs. Thus, while these variable appear to have little significance, they, in fact, have large significance since they are able to "switch-off" dose. When changed enough to "switch-on" dose their effect as a variable is weak.

Some variables were found to have no significant impact on the System Model results over their considered ranges. Layers in soil column (variable C in air path study and variable B in water path study) fell into this category. Apparently, the retardation factors of the geology are the drivers for the model and the number of soil layers makes little or no difference in dose output. It is felt that the number of layers acts only as a delay factor which would be important for short-lived or intermediate range half life isotopes. For most cases, this variable will have no impact. Thus, a "smeared out" approach to soil column geology would probably introduce very little error in the results.

Aquifer dispersion (variable G in water path study) is another variable which seems only to delay dose output but does not significantly impact cumulative population dose. The variable demography (variable D in air path study) represents the population distance distribution and was found to be insignificant. This is probably due to a large percentage of the population dose coming from the food chain rather than cloud shine or ground shine or inhalation. Trucks transporting foods acted as a distance nullifier and resulted in population distance not being a significant variable. Note that total population was held constant since it is obvious that population dose will be proportional to the total population. It was also necessary to hold the age distribution constant to reduce the number of independent variables. It is well-known that moving the age scale down toward younger people increases the dose commitment.

Weather was important to the models primarily from a switch standpoint. Rainy weather was necessary for the water path sensitivity study to have results and dry, windy weather was necessary for the air path to accumulate a dose. Agriculture (variable B in the air path study) was found to be a significant contributor to the model. Also, nuclide quantity (variable I in air path and D in water path study) was found to be significant in the water path results. This variable was set constant in the air path study in order to obtain information about stack height (variable J in air path study). Stack height was found to be significant in the air path results along with nuclide solubility.

Many interactions were identified as being significant in the sensitivity studies. Significant interactions indicate that the effect that a variable has on the results is dependent on the value of another interacting variable. Thus a combined effect of two interacting variables is not just additive but more like being multiplicative. Significant interaction can dominate the individual effects of the interacting variables. Thus, many of the variables in the studies are not individually significant due to the significance or their interactions with other variables.

For the air path sensitivity study, the significant interactions are discussed below. Weather X cap characteristics (variable A and E) interaction indicates an important relationship between wind and rain with the geometry and spacing of the caps on the trenches. Soil size X burial depth and soil size X site wind resistance and burial depth X site wind resistance (variables F, G, and K) interactions reflect the relationships involved in the erosion portion of the air path study. Burial depth X retardation factor (variables G and L) interaction is another significant relationship.

The water path sensitivity study also had significant interactions. Water travel time X nuclide solubility and water travel time X water body turnover flowrate and nuclide solubility X water turnover body flowrate (variables E, H, and I) interactions show the importance of the combined effects. For example, if the nuclide is very soluble and the aquifer is very slow, no effect will be seen. If the nuclide is insoluble and the aquifer is fast following, still no effect is seen. A dose results when the aquifer is traveling fast and the nuclide is soluble. Therefore, where reasonable soil or aquifer retention (delay) exists, there would be little difference between dissolved nuclides and insoluble nuclides in the trench. This is a significant result especially considering that it is found at very low Kds.

In summary, the sensitivity studies have indicated that the Systems Model is driven by several key variables. Other variables of little importance can be assigned constant values or do not need very accurate input. It should be noted that the analysis in these studies did not look at site exposures. This means that high soil surface (or near surface) concentrations at the site show no signficance since direct exposure was not included in the study. however, it can be concluded that direct effects will be essentially proportional to surface/near surface concentrations. Also, as discussed above, many variables had to be assigned exaggerated values in order to obtain model results. Thus, it appears that burial systems even with weak retention parameters display very resistance to transport. Movement results generally from gross washout or flooding (as in Maxey Flats or West Valley) and not when a good soil path is provided and trenches are properly covered.

8. REFERENCE FACILITY DOSE ASSESSMENT

8.1 INTRODUCTION

8.1.1 Background

The purpose of this project was to develop a means to analyze the radiological effects of proposed low-level-waste burial sites, burial procedures and associated activities. The objective of this effort is to develop a computer program and data base to calculate population dose for a broad spectrum of radionuclide release events and conditions, ranging from a short-term event such as a fire in the burial pit or transport vehicle to a long-term event involving the transport of dissolved radionuclides in ground water flows over periods of tens of thousands of years.

The Task 4 activities reported in this section represent work to define and describe test cases to (1) demonstrate the use of the model and (2) to give users a check on versions of the code converted to run on their machine. Two reference shallow-land burial sites were defined and 10 test cases associated with those sites were developed to demonstrate and test different parts of the code.

8.1.2 Relationship to Other Tasks

In Task 1, several existing shallow land burial (SLB) sites were visited and literature reviewed to assess the problems of shallow land burial. Potential release pathways from SLB sites and potential radionuclide inventories subject to release were defined.

In Task 2, the shallow land burial analysis model was developed. This effort consisted largely of assembling and evaluating existing models for the various pathways and adapting them for use in a systems model. In some cases, entire computer codes were used with some modification, while in other cases only the core theory of existing models were retained and a new subprogram was constructed. The Task 2 report describes the model in detail.

In Task 3, the sensitivity of calculated results to the various parameters was tested by running the code with statistically-sampled variations of code input parameters. In this manner, those parameters which most strongly impacted the first result (population dose) were identified.

8.1.3 Approach

The intent in selection of demonstration test cases was to use realistic data and thereby derive answers which are indicative of potential population doses from low-level waste burial activites. It was necessary, however, to take into account two constraining factors, code run time and magnitude of the answer. Some SLB problems are very quick running, but some problems involving the chronic release and transport of multiple radionuclides over a period of many (e.g., tens of thousands) years can be long running. Test cases which will be used by persons to check the operation of the code on their machine should run, at most, a few minutes CPU.

For low-level wastes, population doses from chronic or accidental release are usually low, but for some pathways and conditions, the dose is so low that the computer derives only zeros, even with the result printed on "E" format. In the case of chronic releases to air and water, intermediate results are given for soil concentrations since no "real" inputs could be made to produce non-zero dose results.

Ten cases were derived to demonstrate different types of code application. The test case for calculating the dose to a person at the edge of the SLB pit is very quick running and exercises the DIRECT dose subroutine. For this case, a detailed description of site characteristics (meteorology, demography, crops, soil and aquifer) was not needed. The analysis of the radiological effects of a fire in a waste transport vehicle is also fast running and involves the use of the ATMOS air tranport routine and the DOSET population dose routine. The analysis of long-term releases via ground water, is slower running and involves the repeated application of the UNSAT unsaturated zone transport subprogram, the AQUIFER aquifer transport subprogram and the ATMOS and DOSET subprograms. Stack releases from the incinerator are obtained by using ATMOS and DOSET.

Detailed description of the reference sites used can be found in Section 8.2 and details of the results obtained are in Section 8.3.

8.2 REFERENCE SITES

Two reference sites were described for the demonstration cases; a semi-arid site and a wet climate site. It was felt that two sites were necessary in order to fully illustrate operation of the model. Some scenarios used would not actually occur at the burial ground (such as an on-the-road truck accident or release from packaging plant). In these cases, the meteorology and demography of one of the sites was used for the purposes of the demonstration.

An effort was made to make the sites realistic. Therefore, much of the data is taken from real locations with some necessary adjustments and simplifications. The sources of data along with the relationship of the data to real features of sites are identified in the site descriptions. Where data could not be found, estimates were made and identified as such.

8.2.1 Semi Arid Site (Site No. 1)

Typical existing DOE or commercial semi-arid or arid sites are located at Hanford, Idaho Falls, and Beatty. Most of the semi-arid site characteristics are borrowed from these with emphasis on Hanford and Idaho Falls. (In some ways, Beatty is in a class by itself). Most of the data needed could be readily obtained from information published on these sites.

8.2.1.1 Meteorology

The rainfall pattern used for this site is based on a typical year at Idaho Falls. Monthly rain of 0.72 inches is assumed to occur over a five-day period followed by a 25-day dry period (i.e., 8.6 inches of rain per year). Soil evaporation of about 7.2 inches occurs over a 25-day dry period. The cycle reports each month.

Wind velocity/stability frequency data are taken from the Hanford High Performance Fuel Laboratory (HPFL) EIS. Wind data for the site are given in Table 8-1. The mean annual temperature used was 11°C which is for Hanford in 1972.

Table 8-1. Wind Frequency Data for Semi-Arid Site (No. 1).

Velocity m/sec	0.67	2.46	4.47	6.93	9.61	12
Stability class						
A	0.17	0.0361	0.021	0.0135	0.0071	0.0052
B	0.17	0.0361	0.021	0.0136	0.0071	0.0052
C	0.171	0.0362	0.0211	0.0136	0.0071	0.0053
D	0.0487	0.0294	0.0226	0.0194	0.0117	0.0095
E	0.0277	0.0304	0.0429	0.0602	0.0327	0.0167
F	0.0393	0.0503	0.0597	0.0506	0.0182	0.0085
G	0.0254	0.0351	0.0382	0.0205	0.0019	0.0002

8.2.1.2 Demography

A one-dimensional population distribution was assumed which is typical of the semi-rural region with nearby small population centers. The distribution used is actually the same as for the wet site which was a year 2000 projection for a 22.5^0 sector due east of the Savannah River Plant. Table 8-2 gives the demography.

8.2.1.3 Hydrology

A nearby river, 41 Km away, has a flowrate of $9\text{x}10^{13}$ l/yr (10^5 cfs). These are numbers corresponding to the Columbia river and Hanford reservation 200 area burial grounds. The principal aquifer lies 350 feet below the surface and flows an average of $1.8\text{x}10^{-4}$ m/sec (50 ft/day). The depth corresponds to Hanford. The flowrate is large compared to most arid region aquifers but would give conservative results. The aquifer dispersion coefficient is assumed to be $1\text{x}10^{-3}$ cm^2/sec which is a typical value for western desert soils. The aquifer bulk density is 1.7 gm/cc and void fraction is 0.5. Table 8-3 gives sorption equilibrium coefficients for nuclides in the aquifer.

8.2.1.4 Agronomy and Topography

Surface till is assumed to be sandy fulviatile and glaciofluvatile sediments composed of 95 percent aggregates smaller than 0.84 mm diameter. Surface roughness features are assumed to be 0.1 m high. The knollslope of trench caps is assumed to be 8 feet high with a 60-foot half width or, therefore, 14 percent. The percentage of soil remaining suspended when lifted is assumed to be 70 percent.

No wind barrier is present at the site. The prevailing wind is assumed to be from 50^0 and the field angle to the wind is 50^0. A field area typical of Beatty is assumed (1200 ft wide by 1600 ft long). Vegetation cover on the site is assumed to be 10^{-3} kg/m^2.

Table 8-2. Distribution of Population Along Prevailing Wind Path for Site Nos. 1 and 2.

Distance (Km)	Population
16	0
32	3000
48	9000
64	5000
80	8000
100	6000
120	10000

Table 8-3. Nuclide Equilibrium Coefficients* in the Aquifer (Note: All isotopes of the same element have the same coefficient)

Element	Equilibrium Constant
H	1
C	340
S	340
Cr	35
Mn	35
Fe	510
Co	340
Ni	340
Zn	340
Sr	8
Zr	340
Nb	340
Tc	1.3
Ru	1021
Sb	10
I	1.3
Cs	70
Ce	340
Eu	4100
Ra	170
Th	4100
U	8
Np	240
Pu	680
Am	240
Cm	240

*$K = 1 + \frac{KdP}{\varepsilon}$ Where K = equiv. coeff., Kd = retardation factor
P = bulk density (1.7 gm/ml)
ε = void fraction (0.5)

8.2.1.5 Vadose Zone

The unsaturated zone between the trenches and the aquifer (vadose zone) is 350 feet deep (Hanford) with the first 200 feet being fulviatile and glaciofluvatile sediments. The next 60 feet is made up of so-called Palouse soil which is a fine sand and silt. The bottom 90 feet of the zone is coarse silt, sand, gravel, and clay (the Ringold Formation at Hanford). Properties for these layers are summarized in Table 8-4. Nuclide retardation factors (K_d's) for the layers are given in Table 8-5.

8.2.1.6 Agriculture

The fraction of land under agriculture in the vicinity of Site Number 1 is 0.1 with two crops per year. The harvest is 100 Kg/Km^2 of leafy green vegetables in one year. There are 50 beef cattle per km^2 on the average and 10 dairy cows per km^2.

8.2.2 Wet Site (Site No .2)

The reference wet site is modeled after the Savannah River Plant. Most of the characteristics used were taken from the SRP EIS for high-level waste. Weather (wind and rainfall) and much of the hydrological and agricultural data are taken from the EIS.

8.2.2.1 Meteorology

An annual rainfall of 47 inches (at SRP) is distributed as a monthly rain of 3.9 inches. Each month the rain occurs over a 20-day period with a 10-day dry period. An evaporation of .29 inches occurs during the dry period. The 20-10 day cycle is assumed to repeat each month. Wind data for the site are given in Table 8-6. The mean annual temperature is 18°C.

Table 8-4. Composition of the Unsaturated Zone (vadose) Above the Water Table. Semi-Arid Site (Site No. 1)

No.	Layer Description	Depth (ft)	Relative Water Conductivity	Bulk Density (gm/cc)
1	Sandy sediments fulviatile and glaciofluviatile	200	1.0	1.77
2	Palouse Soil (Fine sand and silt)	60	0.3	1.73
3	Ringold Formation	90	0.2	1.8

Table 8-5. Nuclide Retardation Factors In Semi-Arid Site (No. 1)
Unsaturated Zone.
(Note: all isotopes of same element have the same value)

Kd (ml/gm)

Element	Zone #1 (top)	Zone #2	Zone #3 (bottom)
H	0	0	0
C	100	100	300
S	100	100	300
Cr	10	10	100
Mn	10	10	100
Fe	150	150	1500
Co	100	100	1000
Ni	100	100	1000
Zn	100	100	1000
Sr	2	2	20
Zr	100	100	1000
Nb	100	100	1000
Tc	0.1	0.1	1
Ru	300	300	300
Sb	3	3	3
I	0.1	0.1	1
Cs	20	20	200
Ce	100	100	300
Eu	1200	1200	10000
Ra	50	50	500
Th	1200	1200	10000
U	2	2	4
Np	70	70	700
Pu	200	200	2000
Am	70	70	700
Cm	70	70	700

Table 8-6. Wind Frequency Data for Wet Site (No. 2).

Velocity m/sec	0.35	1.11	2.0	2.89	4.25	6.72
Stability class						
A	0.	0.00128	0.00432	0.00397	0.00304	0.
B	0.	0.00794	0.02744	0.01214	0.00385	0.00012
C	0.	0.00899	0.00230	0.00864	0.00269	0.
D	0.01693	0.13031	0.09633	0.05126	0.04075	0.00339
E	0.10426	0.09727	0.02300	0.0308	0.00420	0.00035
F	0.12085	0.01857	0.00175	0.00012	0.00012	0.
G	0.16371	0.00724	0.00023	0.	0.0	0.

8.2.2.2 Demography

The population distribution for the wet site is the same as for the semi-arid site which was given in Table 8-2. This is actual data for a 22.5° sector centered on due east from SRP as projected for year 2000.

8.2.2.3 Hydrology

The nearest large river is 1.6×10^{4} m away (distance from SRP burial grounds to the Savannah River) with a flowrate of 9×10^{12} l/yr (10,000 cfs). The principal aquifer closest to the surface is 50 feet below the surface with an average flow velocity of 4×10^{-4} m/sec. The dispersion coefficient is assumed to be 1×10^{-3} cm^2/sec. The aquifer bulk density is 1.7 gm/cc with a void fraction of 0.5.

Sorption equilibrium coefficients for the aquifer are the same as those for the Site No. 1 aquifer. These were given in Table 8-3.

8.2.2.4 Agronomy and Topography

The surface soil is a clay, sand, gravel mixture with fine organic particle content. Particles of less than 0.84 mm diameter comprise 15 percent of the surface soil. Surface roughness is assumed to be 0.01 m on the average. The knollslope of trench caps is 14 percent. The amount of soil remaining suspended when lifted by wind is 20 percent.

No wind barrier is present at the site. The prevailing wind is from 25° and the angle of the trench caps to the wind 0°. As with Site No. 1, the trench cap area is represented by a 1200 foot wide by 1600 foot long site area. Vegetation on the site is 0.2 kg/m^2.

8.2.2.5 The Vadose Zone

The 50 foot deep unsaturated zone is composed of uniform material composed of a clay-sand mixture. The bulk density if 1.7 gm/cc. Nuclide retardation factors for the unsaturated zone are given in Table 8-7.

Table 8-7. Nuclide Retardation Factors In Wet Site (No. 2) Unsaturated Zone.
(Note: all isotopes of the same element have the same value)

Element	Kd (ml/gm)
H	0
C	100
S	100
Cr	10
Mn	10
Fe	150
Co	100
Ni	100
Zn	100
Sr	2
Zr	100
Nb	100
Tc	0.1
Ru	300
Sb	3
I	0.1
Cs	20
Ce	100
Eu	1200
Ra	50
Th	1200
U	2
Np	70
Pu	200
Am	70
Cm	70

8.2.2.6 Agriculture

The fraction of land under agriculture in the vicinity of the wet site is 0.30 (taken from the SRP-HLW EIS). A two crops/year harvest yields 5×10^{-5} kg per km^2 of leafy green vegetables. There are 10 beef cattle per km^2 and 20 dairy cows per km^2 on the average.

8.3 RESULTS

8.3.1 Description of Cases

Eight basic scenarios giving ten cases (two sites for two of the scenarios) were chosen for the demonstration runs. These covered packaging, transportation, burial operations, and post- burial. Where applicable, the two separate sites were examined. The eight basic scenarios were:

- 0-4 Accident stack release from incinerators large volume - filtered
- 0-5 Accident stack release from incinerators small volume - unfiltered
- A-11 Chronic escape to the atmosphere during pre-entry inspection of loads
- B-2 Exposure of personnel to an improperly shielded package (High Intensity)
- C-6 Exposure of personnel to uncovered trench area
- E-1 Chronic release to atmosphere from burial ground due to wind erosion of the soil
- E-2 Chronic release to water sources from the burial ground
- T-2 Truck accident accident on the road with major fire, explosion involving the entire truck including all waste and vehicle fuel supply.

Table 8-8 summarizes inputs and results for the cases studied. The detailed results are given in the computer output at the end of this section.

8.3.2 Releases From Incinerator Stack

This scenario is related to a packaging operation where the waste is burned and then fixed in some matrix (such as bitumen). Case 1 represents release of a fraction of material due to some incident but with proper stack filtering involving packaging plant waste (**WS-4). This scenario number 133 yields a total integrated population dose of 2.44×10^4 man-rem for a 14,000 population. The principal nuclides responsible are CS 137 (8×10^2 man-rem), CS 134 (10^3 man-rem), Np 237 (10^2 man-rem) and Pu 242 (2×10^4 man-rem). The main biological paths are direct inhalation (10^2 man-rem) leafy vegetable ingestion (1.4×10^3 man-rem) resuspension inhalation (2×10^4 man-rem) milk ingestion (2.4×10^2 man-rem) and ground shine (4×10^2 man-rem).

Case 2 is similar but much more severe since the stack is not filtered. All of the same biological paths and nuclides are important but the effect is about 3.5 times larger.

8.3.3 On-Site Activities

Cases 3, 4, and 5 all relate to direct exposure of personnel to waste material. Case 3 is a problem of atmospheric transport due to waste disturbed by inspectors while Cases 4 and 5 are shine exposures.

Case 3 is scenario 40 involving exposure due to loose material escaping during inspection from a large box containing reactor decomissioning, decontamination waste. Most of the contribution is from Co-60 (6×10^{-6} man-rem) and the major path is ground shine. Some minor exposure from ingestion paths is also present.

Case 4 is scenario 44 involving accidental exposure from inadvertent shielding removal from a high intensity load (Co-60, 3000 Ci). The exposure is large: 7 rem to any workers within 3 m for 2 min.

**Note: See Volume 1 of this report for inventory descriptions

Table 8-8. Summary of Cases Studied
Population: 41,000

Case No.	Scenario No.	Title No.	Inventory**	Input Data	Path*	Cumulative Dose (man-rem)	Direct Shine (rem)
1	133	O-4	WS-4	Volume = 14,000m^3 560 hrs exposure 100ft stack Site #1 wind	2	2.4 E + 4	
2	134	O-5	WS-4	Volume = 25m^3 1 hr exposure 100 ft stack Site #1 wind	2	7.8 E + 4	
3	40	A-11	WS-3	Volume = 1m^3 2 min exposure Site #1	2	6.6 E - 6	
4	44	B-2	WS-1	Line Source 10m Distance = 3m 2 min exposure ¼" steel container	3		7.0 E + 0
5	98	C-6	WS-6	Volume = 2100m^3 Distance = 50m 2 min exposure 1/16" Aluminum	3		7.3 E - 8
6	111	E-1	WS-6	Site #1 10 yr exposure	951	0.0 E + 0	
7	111	E-1	WS-6	Site #2 10 yr exposure	951	0.0 E + 0	
8	112	E-2	WS-6	Site #1 10 yr exposure	91	0.0 E + 0	
9	112	E-2	WS-6	Site #2 10 yr exposure	91	0.0 E + 0	
10	139	T-2	WS-2	30 min exposure Heat Release = 5x10^{6}BTU Volume = 90m^3 Site #1 wind	3		1.42 E - 4
					2	1.2 E + 2	

*Path Codes: 2 = atmospheric, 3 = shine, 91 = seepage to aquifer, 951 = seepage, wind erosion

**Note: Inventories have been renumbered since Task 2 Report. See Tables 4-2 through 4-6

Case 4 is also a shine case but less severe than Case 3. The source is a section of exposed trench (2100 m^3 volume of waste) or inventory WS-6. This is of the nature of routine exposure and is $7.3x10^{-8}$ rem at a 10 m distance assuming equivalent average shielding similar to 1/16" of aluminum.

8.3.4 Routine Transport From Wind and Rain

Cases 6 through 9 involve routine influence of weather or buried waste at Site No.1 (semi-arid) and Site No. 2 (wet). In all of these cases, the quantity of nuclides entering the biosphere was too small to calculate a dose. In Case 7, a detailed output of soil and water concentrations from UNSAT (called "HYDRO OUTPUT") is provided to show what happens to nuclides.

Cases 6 and 7 are calculations involving seepage of water to trenches, dissolving waste, carrying nuclides to surface by evapotranspiration and carrying them to the atmosphere by wind erosion. The second page of Case 6 shows the atmospheric concentration. The largest are from Fe-55, Co-60, Co-58, Cr-51, and Cs 134. These very low concentrations are not sufficient to give measurable dose. Case 7 is similar. Examination of detailed output, especially soil concentration**, shows how nuclides are tightly bound to the solid or are carried to the aquifer.

Cases 8 and 9 also give no population dose since the inputs to the water paths are again very small and the half lives of most nuclides escaping are such that they decay before reaching the biological path.

8.3.5 Vehicle Accident

Case 10 is scenario 139, a major truck accident with a truck carrying LWR operational waste (WS-2). It is assumed that the truck is totally consumed by fire and two percent of the waste is released to the atmosphere. Dose from direct shine is found to be negligible while a population dose of about 120 man-rem results from atmospheric transport. Most of this dose is due to Cm-244, Co-58, Cs-137, Cs-134, Sr-90, Np-237, and Mn-54 and 80 percent is due to the inhalation of resuspended material.

**These are the tables of "DD" versus mCi/gm of each nuclide found at the end of each time step output

DETAILED RESULTS

Note: "MREM" in these outputs means man-rem not millirem.

CASE 1

```
   TEST CASES FOR REPORT [illegible] 11/6/80

SCENARIO NUMBER 8133

WASTES EXITING AFTER PROPER DISPOSAL AT BURN SITE.


      INVENTORY IWS-4

       PATH            RELEASE
                       FRACTION
       2000             0.1E-05
       2  ATMOSPHERIC TRANSPORT
```

```
          PATH NUMBER    1
   NUCLIDE      AMOUNT
                CI/M**3

     CR51     4.480E-06
     CO58     4.480E-06
     FE55     4.480E-06
     ZN65     2.240E-07
     ZR95     2.240E-07
     RU106    2.240E-07
     SB124    2.240E-07
     SB125    2.240E-07
     EU152    4.480E-10
     EU154    4.480E-09
     EU155    4.496E-09
     SR90     4.480E-08
     CS137    9.200E-06
     MN54     2.240E-06
     CS134    5.120E-06
     H3       5.440E-07
     C14      2.560E-08
     NI59     6.400E-09
     TC99     6.400E-09
     I129     3.200E-10
     CS135    3.200E-10
     NP237    3.200E-10
     PU238    4.160E-10
     PU239    4.480E-10
     PU240    6.400E-10
     PU241    1.728E-07
     PU242    1.792E-07
     AM241    4.160E-09
     AM242    1.280E-09
     AM243    3.200E-10
     CM242    2.880E-09
     CM243    3.200E-10
     CM244    1.920E-09

 EXPOSURE TIME IS    0.5600E+03HOURS

 VOLUME OF PACKAGE IS    0.1400E+05 CUBIC METERS
```

```
                                   DOSE OUTPUT (MREM)
                                   FOR PATH 1
                                     TEST CASES FOR REPORT NUMBER 4 11/6/80

                   CUMULATIVE POPULATION DOSE        2.44E+04
             DIRECT EXPOSURE DOSE(REM/PERSON)        0.00E+00


          TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
          DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


   RADIONUCLIDE
   CR51      7.34E-01     CO58      5.37E+01
   FE55      2.69E+00     ZN65      4.49E+00
   ZR95      1.22E+00     RU106     1.38E-01
   SB124     3.10E+00     SB125     4.34E+00
   EU152     7.51E-04     EU154     2.72E-01
   EU155     1.51E-02     SR90      6.89E+01
   CS137     8.37E+02     MN54      4.41E+01
   CS134     9.97E+02     H3        5.24E-02
   C14       2.10E-02     NI59      1.44E-02
   TC99      7.84E-04     I129      1.03E-01
   CS135     2.72E-02     NP237     1.42E+02
   PU238     1.08E+00     PU239     3.76E+00
   PU240     2.80E+00     PU241     8.45E+00
   PU242     2.22E+04     AM241     1.11E+01
   AM242     5.33E-06     AM243     1.32E+00
   CM242     4.52E+00     CM243     1.17E+01
   CM244     5.60E+01


   DISTANCE(M)
    1600.    2.90E+02      3200.    4.41E+03
    4800.    7.92E+03      6400.    3.17E+03
    8000.    5.74E+03     10000.    2.16E+03
   12000.    2.72E+03


   PATH
CLOUD SHINE         9.20E-02 GROUND SHINE        3.66E+02
D. INHALATION       1.01E+02 R. INHALATION       2.23E+04
WATER INGESTION     0.00E+00 L. V. INGESTION     1.39E+03
ROOT INGESTION      7.34E-03 MILK INGESTION      2.42E+02
BEEF INGESTION      7.49E+01


    ORGAN
  WHOLE BODY     2.44E+04    BONE              8.83E+05
  LIVER          1.28E+05    KIDNEY            5.41E+04
  GONADS         3.09E+02    LUNG              1.51E+04
  G.I.TRACT      7.59E+02    THYROID           3.87E+02
  SKIN           4.49E+02


    AGE GROUP
     CHILD     5.44E+03        TEEN      3.94E+03
     ADULT     1.50E+04
```

```
                                              TOTAL DOSE OUTPUT (CONT.)
                                                TEST CASES FOR REPORT NUMBER 4 11/6/80

                         CUMULATIVE POPULATION DOSE          2.44E+00
                    DIRECT EXPOSURE DOSE(REM/PERSON)         0.00E+00

                TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
                DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


   RADIONUCLIDE
    CR51       7.36E-01      CO58      5.37E+01
    FE55       2.69E+00      ZN65      4.89E+00
    ZR95       1.22E+00      RU106     1.38E-01
    SB124      3.10E+00      SB125     4.34E+00
    EU152      9.51E-04      EU154     2.72E-01
    EU155      1.51E-02      SR90      6.89E+01
    CS137      8.37E+02      MN54      8.41E+01
    CS134      9.97E+02      H3        5.24E-02
    C14        2.10E-02      NI59      1.41E-02
    TC99       7.89E-04      I129      1.03E-01
    CS135      2.72E-02      NP237     1.42E+02
    PU238      1.60E+00      PU239     3.74E+00
    PU240      2.80E+00      PU241     8.45E+00
    PU242      2.22E+04      AM241     1.11E+01
    AM242      5.33E-06      AM243     1.32E+00
    CM242      4.52E+00      CM243     1.17E+01
    CM244      5.60E+01


   DISTANCE(M)
     1600.     2.94E+02       3200.    4.41E+03
     4800.     7.92E+03       6400.    3.17E+03
     8000.     3.74E+03      10000.    2.16E+03
    12000.     2.72E+03


     PATH
 CLOUD SHINE         9.20E-02 GROUND SHINE       3.66E+02
 D. INHALATION       1.01E+02 R. INHALATION      2.23E+04
 WATER INGESTION     0.00E+00 L. V. INGESTION    1.36E+03
 ROOT INGESTION      7.39E-03 MILK INGESTION     2.42E+02
 BEEF INGESTION      7.69E+01


     ORGAN
   WHOLE BODY    2.44E+04    BONE           8.88E+05
   LIVER         1.20E+05    KIDNEY         9.44E+04
   GONAD         3.69E+02    LUNG           6.51E+04
   G.I.TRACT     7.39E+02    THYROID        3.87E+02
   SKIN          4.49E+02


     AGE GROUP
      CHILD     5.48E+03       TEEN      3.94E+03
      ADULT     1.56E+04
```

CASE 2

```
TEST CASES FOR REPORT NUMBER 4 11/6/80

SCENARIO NUMBER 1134


WASTES ARE NOT FILTERED AT BURN SITE.


        INVENTORY INS=4

         PATH            RELFASE
                         FRACTION
         2000             0.1E+01
         2  ATMOSPHERIC TRANSPORT
```

Moore Business Forms, Inc.

```
        PATH NUMBER  1
     NUCLIDE      AMOUNT
                  CI/M**3

      CR51      4.480E+00
      CO58      4.480E+00
      FE55      4.480E+00
      ZN65      2.240E-01
      ZR95      2.240E-01
      RU106     2.240E-01
      SB124     2.240E-01
      SB125     2.240E-01
      EU152     4.480E-04
      EU154     4.480E-03
      EU155     4.480E-03
      SR90      4.480E-02
      CS137     9.280E+00
      MN54      2.240E+00
      CS134     5.120E+00
      H3        5.440E-01
      C14       2.560E-02
      NI59      6.400E-03
      TC99      [illegible].200E-03
      I129      3.260E-04
      CS135     3.200E-04
      NP237     3.200E-04
      PU238     4.160E-04
      PU239     4.480E-04
      PU240     6.400E-04
      PU241     1.728E-01
      PU242     1.792E-01
      AM241     4.160E-03
      AM242     1.280E-03
      AM243     3.200E-04
      CM242     2.880E-03
      CM243     3.200E-04
      CM244     1.920E-03

EXPOSURE TIME IS   0.1000E+01HOURS

VOLUME OF PACKAGE IS   0.2500E+02 CUBIC METERS
```

```
                                  DOSE OUTPUT (MREM)
                                  FOR P,ID 1
                                    TEST CASES FOR REPORT NUMBER 4 11/6/80

                     CUMULATIVE POPULATION DOSE        7.79E+04
                 DIRECT EXPOSURE DOSE(REM/PERSON)      0.00E+00


            TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
            DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


   RADIONUCLIDE
   CR51      2.35E+00     CO58      1.71E+02
   FE55      8.57E+00     ZN65      1.56E+01
   ZR95      3.90E+00     RU106     4.41E-01
   SB124     9.87E+00     SB125     1.39E+01
   EU152     3.03E-03     EU154     6.66E-01
   EU155     4.83E-02     SR90      2.20E+02
   CS137     2.67E+03     MN54      1.41E+02
   CS134     3.18E+03     H3        1.67E-01
   C14       6.69E-02     NI59      4.60E-02
   TC99      2.52E-03     I129      3.27E-01
   CS135     8.69E-02     NP237     4.53E+02
   PU238     3.44E+00     PU239     1.20E+01
   PU240     8.90E+00     PU241     2.69E+01
   PU242     7.07E+04     AM241     3.55E+01
   AM242     1.70E-05     AM243     8.20E+00
   CM242     1.44E+01     CM243     3.74E+01
   CM244     1.74E+02


   DISTANCE(M)
    1600.    9.38E+02      3200.    1.41E+04
    4800.    2.52E+04      6400.    1.01E+04
    8000.    1.19E+04     10000.    6.90E+03
   12800.    8.67E+03


   PATH
CLOUD SHINE         2.93E-01 GROUND SHINE        1.17E+03
D. INHALATION       3.21E+02 R. INHALATION       7.10E+04
WATER INGESTION     0.00E+00 L. V. INGESTION     4.35E+03
ROOT INGESTION      2.59E-02 MILK INGESTION      7.72E+02
BEEF INGESTION      2.45E+02


   ORGAN
 WHOLE BODY     7.79E+04    BONE            2.82E+06
 LIVER          5.96E+05    KIDNEY          3.01E+05
 GONADS         1.19E+03    LUNG            2.09E+05
 G.I.TRACT      2.36E+03    THYROID         1.21E+03
 SKIN           1.43E+03


   AGE GROUP
    CHILD     1.75E+04        TEEN      1.26E+04
    ADULT     4.79E+04
```

```
                                   TOTAL DOSE OUTPUT (MREM)
                                      TEST CASES FOR REPORT [illegible] 11/6/80

                    CUMULATIVE POPULATION DOSE          7.79E+04
                DIRECT EXPOSURE DOSE(REM/PERSON)        0.00E+00

              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   CR51       2.35E+00     CO58      1.71E+02
   FE55       8.57E+00     ZN65      1.56E+01
   ZR95       3.90E+00     RU106     4.41E-01
   SB124      9.87E+00     SB125     1.39E+01
   EU152      3.03E-03     EU154     6.66E-01
   EU155      4.83E-02     SR90      2.20E+02
   CS137      2.67E+03     MN54      1.41E+02
   CS134      3.18E+03     H3        1.67E-01
   C14        6.69E-02     NI59      4.60E-02
   TC99       2.52E-03     I129      3.27E-01
   CS135      8.69E-02     NP237     4.53E+02
   PU238      3.44E+00     PU239     1.29E+01
   PU240      8.90E+00     PU241     2.69E+01
   PU242      7.07E+04     AM241     3.55E+01
   AM242      1.70E-05     AM243     4.20E+00
   CM242      1.44E+01     CM243     3.74E+01
   CM244      1.79E+02

   DISTANCE(M)
    1600.     9.38E+02      3200.     1.41E+04
    4800.     2.52E+04      6400.     1.01E+04
    8000.     1.14E+04     10000.     6.90E+03
   12000.     8.67E+03

   PATH
CLOUD SHINE          2.93E-01 GROUND SHINE        1.17E+03
D. INHALATION        3.21E+02 R. INHALATION       7.10E+04
WATER INGESTION      0.00E+00 L. V. INGESTION     4.35E+03
ROOT INGESTION       2.54E-02 MILK INGESTION      7.72E+02
BEEF INGESTION       2.15E+02

   ORGAN
 WHOLE BODY     7.79E+04    BONE               2.82E+06
 LIVER          3.94E+05    KIDNEY             5.01E+05
 GONAD          1.14E+03    LUNG               2.04E+05
 G.I.TRACT      2.36E+03    THYROID            1.29E+03
 SKIN           1.43E+03

   AGE GROUP
   CHILD      1.75E+04       TEEN      1.26E+04
   ADULT      4.74E+04
```

CASE 3

```
  TEST CASES FOR REPORT NUMBER 4 11/6/80
SCENARIO NUMBER : 90


CHRONIC ESCAPE TO ATMOSPHERE OF RADIONUCLIDES
DURING THE PRE-ENTRY INSPECTIO


      INVENTORY IMS-3

      PATH          RELEASE
                    FRACTION
1     2000           8.1E-04
      2  ATMOSPHERIC TRANSPORT
```

```
           PATH NUMBER  1
      NUCLIDE      AMOUNT
                   CI/M**3

        FE55      1.368E-06
        CO60      1.243E-05
        NI63      2.015E-05
        NI59      1.292E-07
        C14       1.140E-08
        NB94      1.520E-09

EXPOSURE TIME IS   0.3360E-01HOURS

VOLUME OF PACKAGE IS   0.1000E+01 CUBIC METERS
```

```
                                        DOSE OUTPUT (MREM)
                                        FOR PATH 1
                                           TEST CASES FOR REPORT NUMBER 4 11/6/80

                        CUMULATIVE POPULATION DOSE         6.59E-06
                    DIRECT EXPOSURE DOSE(REM/PERSON)       0.00E+00

               TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
               DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


    RADIONUCLIDE
    FE55       4.00E-09      CO60       5.93E-06
    NI63       6.54E-07      NI59       1.43E-09
    C14        4.60E-11      NB94       0.00E+00

    DISTANCE(M)
     1600.     2.83E-07       3200.     1.05E-06
     4800.     2.11E-06       6400.     7.93E-07
     8000.     8.72E-07      10000.     4.99E-07
    12000.     5.81E-07

    PATH
 CLOUD SHINE        8.96E-10 GROUND SHINE       5.63E-06
 D. INHALATION      2.34E-09 R. INHALATION      1.13E-08
 WATER INGESTION    0.00E+00 L. V. INGESTION    8.65E-07
 ROOT INGESTION     4.45E-12 MILK INGESTION     6.53E-08
 BEEF INGESTION     1.12E-06

    ORGAN
  WHOLE BODY     6.59E-06   BONE           2.54E-05
  LIVER          6.08E-06   KIDNEY         4.51E-06
  GONAD          4.59E-06   LUNG           6.94E-06
  G.I.TRACT      7.08E-06   THYROID        5.01E-06
  SKIN           6.01E-06

    AGE GROUP
     CHILD     1.93E-06       TEEN      9.55E-07
     ADULT     3.70E-06
```

```
                                  TOTAL DOSE OUTPUT (REM)
                                   TEST CASES FOR REPORT NUMBER 4 11/6/80

                      CUMULATIVE POPULATION DOSE          6.59E-06
                  DIRECT EXPOSURE DOSE(REM/PERSON)        0.00E+00


              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


     RADIONUCLIDE
     FE55       8.04E-09      CO60       5.93E-06
     NI63       6.54E-07      NI59       1.43E-09
     C14        4.64E-11      NB94       0.00E+00


     DISTANCE(M)
      1600.     2.83E-07       3200.     1.45E-06
      4800.     2.11E-06       6400.     7.93E-07
      8000.     8.72E-07      10000.     8.99E-07
     12000.     5.81E-07


     PATH
  CLOUD SHINE         8.96E-10 GROUND SHINE       5.63E-06
  D. INHALATION       2.54E-09 R. INHALATION      1.13E-08
  WATER INGESTION     0.00E+00 L. V. INGESTION    8.65E-07
  ROOT INGESTION      9.16E-12 MILK INGESTION     6.53E-08
  BEEF INGESTION      1.02E-08


     ORGAN
    WHOLE BODY     6.59E-06    BONE           2.54E-05
    LIVER          6.08E-06    KIDNEY         4.51E-06
    GONAD          4.59E-06    LUNG           6.98E-06
    G.I.TRACT      7.08E-06    THYROID        5.01E-06
    SKIN           6.61E-06


     AGE GROUP
      CHILD     1.93E-06         TEEN      9.55E-07
      ADULT     3.70E-06
```

Moore Business Forms, Inc.

CASE 4

```
TEST CASES FOR REPORT NUMBER 0 11/6/80

SCENARIO NUMBER : 44


CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN
REMOVING THE LINER,CONTAINING HIGHLY ACTIVATED LWR
 COMPONENTS FROM SHIELDED CASK AND MANIPULATING IT
 INTO THE BURIAL TRENCH.


        INVENTORY I-9-1

         PATH             RELEASE
                          FRACTION
1        3000               0.1E+01
         3  WASTE CONTACT (SPIKE)
```

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READEX FICHE

```
              PATH NUMBER  1
          NUCLIDE      AMOUNT
                       CI/M**3

           CO60     3.000E+03

    EXPOSURE TIME IS   0.3300E-01HOURS

    VOLUME OF PACKAGE IS   0.1000E+02 CUBIC METERS
```

Moore Business Forms, Inc.

```
                                          DOSE OUTPUT (AREA)
                                          FOR PATH 1
                                             TEST CASES FOR REPORT NUMBER 4 11/6/80

                          CUMULATIVE POPULATION DOSE          0.00E+00
                      DIRECT EXPOSURE DOSE(REM/PERSON)        7.05E+00


            TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
            DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


   RADIONUCLIDE
   CO60        0.00E+00


   DISTANCE(M)
      0.       0.00E+00


   PATH
CLOUD SHINE         0.00E+00 GROUND SHINE        0.00E+00
D. INHALATION       0.00E+00 R. INHALATION       0.00E+00
WATER INGESTION     0.00E+00 L. V. INGESTION     0.00E+00
ROOT INGESTION      0.00E+00 MILK INGESTION      0.00E+00
BEEF INGESTION      0.00E+00


   ORGAN
 WHOLE BODY      0.00E+00    BONE          0.00E+00
 LIVER           0.00E+00    KIDNEY        0.00E+00
 GONAD           0.00E+00    LUNG          0.00E+00
 G.I.TRACT       0.00E+00    THYROID       0.00E+00
 SKIN            0.00E+00


   AGE GROUP
    CHILD      0.00E+00       TEEN      0.00E+00
    ADULT      0.00E+00
```

```
                                              TOTAL DOSE OUTPUT (MREM)
                                                TEST CASES FOR REPORT NUMBER 4 11/6/80

                          CUMULATIVE POPULATION DOSE          0.00E+00
                    DIRECT EXPOSURE DOSE(REM/PERSON)          7.05E+00


               TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
               DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


     RADIONUCLIDE
     CO60       0.00E+00


     DISTANCE(M)
        0.      0.00E+00


     PATH
  CLOUD SHINE         0.00E+00 GROUND SHINE        0.00E+00
  D. INHALATION       0.00E+00 R. INHALATION       0.00E+00
  WATER INGESTION     0.00E+00 L. V. INGESTION     0.00E+00
  ROOT INGESTION      0.00E+00 MILK INGESTION      0.00E+00
  BEEF INGESTION      0.00E+00


     ORGAN
   WHOLE BODY     0.00E+00     BONE             0.00E+00
   LIVER          0.00E+00     KIDNEY           0.00E+00
   GONAD          0.00E+00     LUNG             0.00E+00
   G.I.TRACT      0.00E+00     THYROID          0.00E+00
   SKIN           0.00E+00


     AGE GROUP
      CHILD     0.00E+00       TEEN      0.00E+00
       ADULT    0.00E+00
```

CASE 5

```
   TEST CASES FOR REPORT NUMBER 6 11/6/80

 SCENARIO NUMBER 1 98

 CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN THE
  ACTIVITIES IN THE VICINITY OF UNCOVERED WASTES.


        INVENTORY INS-6

         PATH            RELEASE
                         FRACTION
 1       5000             0.1E+01
         5  WASTE CONTACT (SHINE)
```

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```
            PATH NUMBER:  1
         NUCLIDE        AMOUNT
                        CI/M**3

          H3          1.200E-01
          C14         3.800E-03
          S35         8.000E-04
          CR51        4.300E-01
          MN54        2.500E-01
          FE55        4.300E-01
          CO58        4.300E-01
          CO60        1.300E+00
          NI59        1.300E-02
          NI63        2.400E+00
          ZN65        2.000E-02
          SR90        4.800E-03
          NB94        1.400E-04
          ZR95        2.000E-02
          TC99        3.200E-05
          RU106       2.000E-02
          SB124       5.000E-03
          SB125       5.000E-03
          I125        1.500E-03
          I129        6.400E-06
          CS134       4.800E-01
          CS135       3.200E-05
          CS137       8.600E-01
          CE144       2.000E-02
          EU152       4.800E-05
          EU154       4.800E-04
          EU155       4.800E-04
          RA226       1.150E-04
          TH230       7.100E-05
          TH232       8.400E-06
          U235        3.210E-05
          U238        7.100E-04
          NP237       4.600E-08
          PU238       3.200E-04
          PU239       4.300E-05
          PU240       6.700E-05
          PU241       1.650E-02
          PU242       2.800E-07
          AM241       3.900E-05
          AM242       1.600E-06
          AM243       2.100E-06
          CM242       2.500E-03
          CM243       6.000E-07
          CM244       1.900E-04

 EXPOSURE TIME IS    0.3310E-01HOURS

 VOLUME OF PACKAGE IS    1.2100E+04 CUBIC METERS
```

```
                              DOSE OUTPUT (MREM)
                                  FOR PATH 1
                              TEST CASES FOR REPORT NUMBER 4 11/6/80

              CUMULATIVE POPULATION DOSE          0.00E+00
           DIRECT EXPOSURE DOSE(REM/PERSON)       7.51E-08

        TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
        DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   H3          0.00E+00      C14        0.00E+00
   S35         0.00E+00      CR51       0.00E+00
   MN54        0.00E+00      FE55       0.00E+00
   CO58        0.00E+00      CO60       0.00E+00
   NI59        0.00E+00      NI63       0.00E+00
   ZN65        0.00E+00      SR90       0.00E+00
   NB94        0.00E+00      ZR95       0.00E+00
   TC99        0.00E+00      RU106      0.00E+00
   SN126       0.00E+00      SB125      0.00E+00
   I125        0.00E+00      I129       0.00E+00
   CS134       0.00E+00      CS135      0.00E+00
   CS137       0.00E+00      CE144      0.00E+00
   EU152       0.00E+00      EU154      0.00E+00
   EU155       0.00E+00      RA226      0.00E+00
   TH230       0.00E+00      TH232      0.00E+00
   U235        0.00E+00      U238       0.00E+00
   NP237       0.00E+00      PU238      0.00E+00
   PU239       0.00E+00      PU240      0.00E+00
   PU241       0.00E+00      PU242      0.00E+00
   AM241       0.00E+00      AM242      0.00E+00
   AM243       0.00E+00      CM242      0.00E+00
   CM243       0.00E+00      CM244      0.00E+00

   DISTANCE(M)
       0.      0.00E+00

   PATH
 CLOUD SHINE       0.00E+00 GROUND SHINE       0.00E+00
 D. INHALATION     0.00E+00 R. INHALATION      0.00E+00
 WATER INGESTION   0.00E+00 L. V. INGESTION    0.00E+00
 ROOT INGESTION    0.00E+00 MILK INGESTION     0.00E+00
 BEEF INGESTION    0.00E+00

   ORGAN
  WHOLE BODY     0.00E+00   BONE          0.00E+00
  LIVER          0.00E+00   KIDNEY        0.00E+00
  GONAD          0.00E+00   LUNG          0.00E+00
  G.I.TRACT      0.00E+00   THYROID       0.00E+00
  SKIN           0.00E+00
```

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```
ADHT 1    0.0uF+00
```

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```
                                   TOTAL DOSE OUTPUT (MREM)
                                 TEST CASES FOR REPORT NUMBER 9 11/6/80

                     CUMULATIVE POPULATION DOSE           0.00E+00
                 DIRECT EXPOSURE DOSE(REM/PERSON)         7.31E-08

            TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
            DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   H3          0.00E+00      C14        0.00E+00
   S35         0.00E+00      CR51       0.00E+00
   MN54        0.00E+00      FE55       0.00E+00
   CO58        0.00E+00      CO60       0.00E+00
   NI59        0.00E+00      NI63       0.00E+00
   ZN65        0.00E+00      SR90       0.00E+00
   NB94        0.00E+00      ZR95       0.00E+00
   TC99        0.00E+00      RU106      0.00E+00
   SB124       0.00E+00      SB125      0.00E+00
   I125        0.00E+00      I129       0.00E+00
   CS134       0.00E+00      CS135      0.00E+00
   CS137       0.00E+00      CE144      0.00E+00
   EU152       0.00E+00      EU154      0.00E+00
   EU155       0.00E+00      RA226      0.00E+00
   TH230       0.00E+00      TH232      0.00E+00
   U235        0.00E+00      U238       0.00E+00
   NP237       0.00E+00      PU238      0.00E+00
   PU239       0.00E+00      PU240      0.00E+00
   PU241       0.00E+00      PU242      0.00E+00
   AM241       0.00E+00      AM242      0.00E+00
   AM243       0.00E+00      CM242      0.00E+00
   CM243       0.00E+00      CM244      0.00E+00

   DISTANCE(M)
      0.     0.00E+00

   PATH
CLOUD SHINE        0.00E+00 GROUND SHINE       0.00E+00
D. INHALATION      0.00E+00 R. INHALATION      0.00E+00
WATER INGESTION    0.00E+00 L. V. INGESTION    0.00E+00
MEAT INGESTION     0.00E+00 MILK INGESTION     0.00E+00
BEEF INGESTION     0.00E+00

   ORGAN
 WHOLE BODY     0.00E+00    BONE          0.00E+00
 LIVER          0.00E+00    KIDNEY        0.00E+00
 GONAD          0.00E+00    LUNG          0.00E+00
 G.I.TRACT      0.00E+00    THYROID       0.00E+00
 SKIN           0.00E+00

   AGE GROUP
    CHILD      0.00E+00       TEEN      0.00E+00
    ADULT      0.00E+00
```

CASE 6

```
TEST CASES FOR_REPORT NUMBER 4 11/6/90 SITE 1

SCENARIO NUMBER 1111

EROSION OR WASHING OUT OF BACKFILL INADEQUATE
BACKFILL DEPTH.

      INVENTORY INS=0

       PATH          RELEASE
                     FRACTION
1      9510           0.3E-02
       9  UNSATURATED ZONE WATER TRANSPORT
       5  WIND EROSION
       1  AQUIFER TRANSPORT
```

```
                PATH NUMBER  1
         NUCLIDE      AMOUNT
                      CI/M**3

         H3         3.600E-08
         C14        1.140E-05
         S35        2.500E-06
         CR51       1.290E-03
         MN54       7.500E-04
         FE55       1.290E-03
         CO58       1.290E-03
         CO60       3.900E-03
         NI59       3.900E-05
         NI63       7.200E-03
         ZN65       6.000E-05
         SR90       1.440E-05
         NB94       4.200E-07
         ZR95       6.000E-05
         TC99       9.600E-08
         RU106      6.000E-05
         SB124      1.500E-05
         SB125      1.500E-05
         I125       4.500E-06
         I129       1.920E-08
         CS134      1.440E-03
         CS135      9.600E-08
         CS137      2.500E-03
         CE144      6.000E-05
         EU152      1.440E-07
         EU154      1.440E-06
         EU155      1.440E-06
         RA226      3.450E-07
         TH230      2.130E-07
         TH232      2.520E-08
         U235       9.600E-08
         U238       2.130E-06
         NP237      1.300E-10
         PU238      9.600E-07
         PU239      1.290E-07
         PU240      2.010E-07
         PU241      4.950E-05
         PU242      7.200E-10
         AM241      9.000E-08
         AM242      4.800E-09
         AM243      6.300E-09
         CM242      7.500E-06
         CM243      1.900E-09
         CM244      5.700E-07

 KILL RUN PROBLEM THROUGH UNSAT FOR   0.8760E+05  HOURS

 EXPOSURE TIME IS   0.8760E+05HOURS

 EXPOSURE TIME IS   0.8760E+05HOURS
```

```
                                   DOSE OUTPUT (MREM)
                                   FOR PATH 1
                                      TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 1

                       CUMULATIVE POPULATION DOSE          0.00E+00
                    DIRECT EXPOSURE DOSE(REM/PERSON)       0.00E+00

              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   H3          0.00E+00    C14        0.00E+00
   S35         0.00E+00    CR51       0.00E+00
   MN54        0.00E+00    FE55       0.00E+00
   CO58        0.00E+00    CO60       0.00E+00
   NI59        0.00E+00    NI63       0.00E+00
   ZN65        0.00E+00    SR90       0.00E+00
   NB94        0.00E+00    ZR95       0.00E+00
   TC99        0.00E+00    RU106      0.00E+00
   SN121       0.00E+00    SB125      0.00E+00
   I125        0.00E+00    I129       0.00E+00
   CS134       0.00E+00    CS135      0.00E+00
   CS137       0.00E+00    CE144      0.00E+00
   EU152       0.00E+00    EU154      0.00E+00
   EU155       0.00E+00    RA226      0.00E+00
   TH230       0.00E+00    TH232      0.00E+00
   U235        0.00E+00    U238       0.00E+00
   NP237       0.00E+00    PU238      0.00E+00
   PU239       0.00E+00    PU240      0.00E+00
   PU241       0.00E+00    PU242      0.00E+00
   AM241       0.00E+00    AM242      0.00E+00
   AM243       0.00E+00    CM242      0.00E+00
   CM243       0.00E+00    CM244      0.00E+00

   DISTANCE(M)
    1600.      0.00E+00      3200.    0.00E+00
    4800.      0.00E+00      6400.    0.00E+00
    8000.      0.00E+00     10000.    0.00E+00
   12000.      0.00E+00

    PATH
 CLOUD SHINE        0.00E+00 GROUND SHINE        0.00E+00
 D. INHALATION      0.00E+00 R. INHALATION       0.00E+00
 WATER INGESTION    0.00E+00 L.V. INGESTION      0.00E+00
 ROOT INGESTION     0.00E+00 MILK INGESTION      0.00E+00
 BEEF INGESTION     0.00E+00

    ORGAN
  WHOLE BODY     0.00E+00    BONE          0.00E+00
  LIVER          0.00E+00    KIDNEY        0.00E+00
  GONADS         0.00E+00    LUNG          0.00E+00
  G.I.TRACT      0.00E+00    THYROID       0.00E+00
  SKT.           0.00E+00
```

```
AGE GROUP
CHILD     0.00E+00     TEEN     0.00E+00
ADULT     0.00E+00
```

```
                                    TOTAL DOSE OUTPUT (MREM)
                                       TEST CASES FOR REPORT NUMBER 9 11/6/80 SITE 1

                   CUMULATIVE POPULATION DOSE          0.00E+00
               DIRECT EXPOSURE DOSE(REM/PERSON)        0.00E+00


          TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
          DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


    RADIONUCLIDE
    H3          0.00E+00     C14        0.00E+00
    S35         0.00E+00     CR51       0.00E+00
    MN54        0.00E+00     FE55       0.00E+00
    CO58        0.00E+00     CO60       0.00E+00
    NI59        0.00E+00     NI63       0.00E+00
    ZN65        0.00E+00     SR90       0.00E+00
    NB94        0.00E+00     ZR95       0.00E+00
    TC99        0.00E+00     RU106      0.00E+00
    SB124       0.00E+00     SB125      0.00E+00
    I125        0.00E+00     I129       0.00E+00
    CS134       0.00E+00     CS135      0.00E+00
    CS137       0.00E+00     CE144      0.00E+00
    EU152       0.00E+00     EU154      0.00E+00
    EU155       0.00E+00     RA226      0.00E+00
    TH230       0.00E+00     TH232      0.00E+00
    U235        0.00E+00     U238       0.00E+00
    NP237       0.00E+00     PU238      0.00E+00
    PU239       0.00E+00     PU240      0.00E+00
    PU241       0.00E+00     PU242      0.00E+00
    AM241       0.00E+00     AM242      0.00E+00
    AM243       0.00E+00     CM242      0.00E+00
    CM243       0.00E+00     CM244      0.00E+00


    DISTANCE(M)
     1600.      0.00E+00      3200.     0.00E+00
     4800.      0.00E+00      6400.     0.00E+00
     8000.      0.00E+00     10000.     0.00E+00
    12000.      0.00E+00


    PATH
 CLOUD SHINE       0.00E+00 GROUND SHINE       0.00E+00
 G. INHALATION     0.00E+00 R. INHALATION      0.00E+00
 WATER INGESTION   0.00E+00 L. V. INGESTION    0.00E+00
 ROOT INGESTION    0.00E+00 MILK INGESTION     0.00E+00
 BEEF INGESTION    0.00E+00


    ORGAN
  WHOLE BODY     0.00E+00   BONE          0.00E+00
  LIVER          0.00E+00   KIDNEY        0.00E+00
  GONAD          0.00E+00   LUNG          0.00E+00
  G.I.TRACT      0.00E+00   THYROID       0.00E+00
  SKIN           0.00E+00
```

```
        AGE GROUP
         CHILD      0.00E+00          TEEN      0.00E+00
         ADULT      0.00E+00
```

Moore Business Forms, Inc.

CASE 7

```
    TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 1

  SCENARIO NUMBER 1112

  INTRUSION OF SURFACE WATER, WATER SEEPAGE TO WATER
   TABLE THROUGH BURIED WASTES.

        INVENTORY #NS-6

         PATH             RELEASE
                          FRACTION
 1       9100              0.1E+00
         9  UNSATURATED ZONE WATER TRANSPORT
         1  AQUIFER TRANSPORT
```

```
              BATCH NUMBER   1
        NUCLIDE        AMOUNT
                       CI/M**3

         H3          1.200E-02
         C14         3.800E-04
         S35         8.600E-05
         CR51        4.300E-02
         MN54        2.500E-02
         FE55        4.300E-02
         CO58        4.300E-02
         CO60        1.300E-01
         NI59        1.300E-03
         NI63        2.400E-01
         ZN65        2.000E-03
         SR90        4.800E-04
         NB94        1.400E-05
         ZR95        2.000E-03
         TC99        3.200E-06
         RU106       2.000E-03
         SB124       5.000E-04
         SB125       5.900E-04
         I125        1.500E-04
         I129        6.400E-07
         CS134       4.800E-02
         CS135       3.200E-06
         CS137       9.600E-02
         CE144       2.000E-03
         EU152       4.800E-06
         EU154       4.800E-05
         EU155       4.400E-05
         RA226       1.150E-05
         TH230       7.100E-06
         TH232       8.400E-07
         U235        3.200E-06
         U238        7.100E-05
         NP237       4.600E-09
         PU238       3.200E-05
         PU239       4.300E-06
         PU240       6.700E-06
         PU241       1.650E-03
         PU242       2.400E-08
         AM241       5.000E-06
         AM242       1.600E-07
         AM243       2.100E-07
         CM242       2.500E-04
         CM243       6.000E-08
         CM244       1.400E-05

   WILL BE PROPELLED THROUGH UNSAT FOR   0.4760E+05  HOURS

   EXPOSURE TIME IS   0.8760E+05HOURS
```

```
                                   DOSE OUTPUT (AREA)
                                   FOR PATH 1
                                        TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 1

                     CUMULATIVE POPULATION DOSE        0.00E+00
                 DIRECT EXPOSURE DOSE(REM/PERSON)      0.00E+00

          TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
          DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   H3          0.00E+00     C14          0.00E+00
   S35         0.00E+00     CR51         0.00E+00
   MN54        0.00E+00     FE55         0.00E+00
   CO58        0.00E+00     CO60         0.00E+00
   NI59        0.00E+00     NI63         0.00E+00
   ZN65        0.00E+00     SR90         0.00E+00
   NB90        0.00E+00     ZR95         0.00E+00
   TC99        0.00E+00     RU106        0.00E+00
   SN123       0.00E+00     SB125        0.00E+00
   I125        0.00E+00     I129         0.00E+00
   CS134       0.00E+00     CS135        0.00E+00
   CS137       0.00E+00     CE144        0.00E+00
   EU152       0.00E+00     EU154        0.00E+00
   EU155       0.00E+00     RA226        0.00E+00
   TH230       0.00E+00     TH232        0.00E+00
   U235        0.00E+00     U238         0.00E+00
   NP237       0.00E+00     PU238        0.00E+00
   PU239       0.00E+00     PU240        0.00E+00
   PU241       0.00E+00     PU242        0.00E+00
   AM241       0.00E+00     AM242        0.00E+00
   AM243       0.00E+00     CM242        0.00E+00
   CM243       0.00E+00     CM244        0.00E+00

   DISTANCE(M)
    1600.      0.00E+00       3200.      0.00E+00
    4800.      0.00E+00       6400.      0.00E+00
    8000.      0.00E+00      10000.      0.00E+00
   12000.      0.00E+00

   PATH
CLOUD SHINE           0.00E+00 GROUND SHINE         0.00E+00
D. INHALATION         0.00E+00 R. INHALATION        0.00E+00
WATER INGESTION       0.00E+00 L. V. INGESTION      0.00E+00
ROOT INGESTION        0.00E+00 MILK INGESTION       0.00E+00
BEEF INGESTION        0.00E+00

    ORGAN
  WHOLE BODY      0.00E+00    BONE           0.00E+00
  LIVER           0.00E+00    KIDNEY         0.00E+00
  [illegible]     0.00E+00    LUNG           1.00E+00
  G.I.TRACT       0.00E+00    THYROID        0.00E+00
  SKIN            0.00E+00
```

```
AGE GROUP
 CHILD      0.00E+00          TEEN        0.00E+00
 ADULT      0.00E+00
```

```
                                   TOTAL DOSE OUTPUT (AREA)
                                     TEST CASES FOR REPORT NUMBER # 11/6/79 SITE 1

                   CUMULATIVE POPULATION DOSE       0.00E+00
                DIRECT EXPOSURE DOSE(REM/PERSON)    0.00E+00


              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


     RADIONUCLIDE
     H3         0.00E+00      C14       0.00E+00
     S35        0.00E+00      CR51      0.00E+00
     MN54       0.00E+00      FE55      0.00E+00
     CO58       0.00E+00      CO60      0.00E+00
     NI59       0.00E+00      NI63      0.00E+00
     ZN65       0.00E+00      SR90      0.00E+00
     NB94       0.00E+00      ZR95      0.00E+00
     TC99       0.00E+00      RU106     0.00E+00
     SB124      0.00E+00      SB125     0.00E+00
     I125       0.00E+00      I129      0.00E+00
     CS134      0.00E+00      CS135     0.00E+00
     CS137      0.00E+00      CE144     0.00E+00
     EU152      0.00E+00      EU154     0.00E+00
     EU155      0.00E+00      RA226     0.00E+00
     TH230      0.00E+00      TH232     0.00E+00
     U235       0.00E+00      U238      0.00E+00
     NP237      0.00E+00      PU238     0.00E+00
     PU239      0.00E+00      PU240     0.00E+00
     PU241      0.00E+00      PU242     0.00E+00
     AM241      0.00E+00      AM242     0.00E+00
     AM243      0.00E+00      CM242     0.00E+00
     CM243      0.00E+00      CM244     0.00E+00

     DISTANCE(M)
      1600.     0.00E+00      3200.     0.00E+00
      4800.     0.00E+00      6400.     0.00E+00
      8000.     0.00E+00     10000.     0.00E+00
     12000.     0.00E+00


     PATH
   CLOUD SHINE        0.00E+00 GROUND SHINE       0.00E+00
   D. INHALATION      0.00E+00 R. INHALATION      0.00E+00
   WATER INGESTION    0.00E+00 L. V. INGESTION    0.00E+00
   ROOT INGESTION     0.00E+00 MILK INGESTION     0.00E+00
   BEEF INGESTION     0.00E+00


     ORGAN
    WHOLE BODY      0.00E+00    BONE          0.00E+00
    LIVER           0.00E+00    KIDNEY        0.00E+00
    GONAD           0.00E+00    LUNG          0.00E+00
    G.I.TRACT       0.00E+00    THYROID       0.00E+00
    SKIN            0.00E+00
```

```
AGE GROUP
 CHILD      0.00E+00        TEEN      0.00E+00
 ADULT      0.00E+00
```

CASE 8

```
    TEST CASES FOR REPORT NUMBER : 11/6/80 SITE 2

SCENARIO NUMBER 1111


EROSION OR WASHING OUT OF BACKFILL INADEQUATE
BACKFILL DEPTH.


      INVENTORY 143-6

      PATH          RELEASE
                    FRACTION
1     9510           0.3E-02
      9  UNSATURATED ZONE WATER TRANSPORT
      5  WIND EROSION
      1  AQUIFER TRANSPORT
```

```
          PATH NUMBER  1
     NUCLIDE       AMOUNT
                  (CI/M**3)

      H3        3.600E-04
      C14       1.100E-05
      S35       2.500E-06
      CR51      1.200E-03
      MN54      7.500E-04
      FE55      1.200E-03
      CO58      1.200E-03
      CO60      3.900E-03
      NI59      3.900E-05
      NI63      7.200E-03
      ZN65      6.000E-05
      SR90      1.400E-05
      NB94      4.200E-07
      ZR95      6.000E-05
      TC99      9.600E-08
      RU106     6.000E-05
      SB124     1.500E-05
      SB125     1.500E-05
      I125      4.500E-06
      I129      1.920E-08
      CS134     1.400E-03
      CS135     9.600E-04
      CS137     2.500E-03
      CE144     6.000E-05
      EU152     1.400E-07
      EU154     1.400E-06
      EU155     1.400E-06
      RA226     3.450E-07
      TH230     2.150E-07
      TH232     2.520E-08
      U235      9.600E-08
      U238      2.130E-06
      NP237     1.380E-10
      PU238     9.660E-07
      PU239     1.240E-07
      PU240     2.010E-07
      PU241     4.950E-05
      PU242     7.200E-10
      AM241     4.000E-04
      AM242     4.800E-09
      AM243     6.300E-09
      CM242     7.500E-06
      CM243     1.800E-09
      CM244     5.700E-07

 WILL RUN PROBLEM THROUGH URSAT RUN    0.8760E+05  HOURS
```

```
                         HYDRO  INPUT

     K      TEH       NO       IN COMNUC
     9      493       52        7     44

   WATER       POTENTIAL  CONDUCTIVITY DIFFUSIVITY                 WATER       POTENTIAL  CONDUCTIVITY DIFFUSIVITY
 0.0000E+00 -1.0000E+06   4.3640E-07   8.1170E-02              5.2000E-02 -3.1360E+03   9.1140E-03   5.6127E+01
 2.0000E-03 -8.1400E+05   6.3050E-07   1.9840E-01              5.4000E-02 -2.4170E+03   1.3780E-02   6.6062E+01
 4.0000E-03 -6.6000E+05   9.1140E-07   3.3980E-01              5.6000E-02 -1.8420E+03   1.9050E-02   7.6635E+01
 6.0000E-03 -5.3500E+05   1.3180E-06   5.0355E-01              5.8000E-02 -1.4340E+03   2.7530E-02   8.8410E+01
 8.0000E-03 -4.3400E+05   1.9050E-06   6.4595E-01              6.0000E-02 -1.1000E+03   3.9800E-02   1.0155E+02
 1.0000E-02 -3.5200E+05   2.7540E-06   9.2178E-01              6.2000E-02 -8.5100E+02   5.7490E-02   1.1610E+02
 1.2000E-02 -2.8400E+05   3.9790E-06   1.1924E+00              6.4000E-02 -6.5500E+02   8.3130E-02   1.3239E+02
 1.4000E-02 -2.3100E+05   5.7490E-06   1.4971E+00              6.6000E-02 -5.0500E+02   1.2020E-01   1.5042E+02
 1.6000E-02 -1.8700E+05   1.3180E-06   1.5550E+00              6.8000E-02 -3.8900E+02   1.7370E-01   1.7057E+02
 1.8000E-02 -1.5200E+05   1.2020E-05   1.9757E+00              7.0000E-02 -3.0000E+02   2.5090E-01   1.9290E+02
 2.0000E-02 -1.2300E+05   1.7370E-05   2.4795E+00              7.2000E-02 -1.7600E+02   3.6280E-01   2.3789E+02
 2.2000E-02 -1.0000E+05   2.5110E-05   3.0574E+00              7.4000E-02 -1.0300E+02   5.2410E-01   2.7615E+02
 2.4000E-02 -8.1000E+04   3.6300E-05   3.7467E+00              7.6000E-02 -6.0600E+01   7.5820E-01   3.0829E+02
 2.6000E-02 -6.6000E+04   5.2490E-05   4.5341E+00              7.8000E-02 -3.5600E+01   1.0960E+00   3.3569E+02
 2.8000E-02 -5.3000E+04   7.5820E-05   5.5147E+00              8.0000E-02 -2.0900E+01   1.5940E+00   3.5890E+02
 3.0000E-02 -4.3000E+04   1.0960E-04   6.6157E+00              8.2000E-02 -1.2200E+01   2.2910E+00   3.7891E+02
 3.2000E-02 -3.5000E+04   1.5870E-04   7.8455E+00              8.4000E-02 -7.2000E+00   3.3090E+00   3.9540E+02
 3.4000E-02 -2.8000E+04   2.2910E-04   9.3890E+00              8.6000E-02 -4.2000E+00   4.7870E+00   4.0982E+02
 3.6000E-02 -2.3000E+04   3.3100E-04   1.1140E+01              8.8000E-02 -2.5000E+00   6.0160E+00   4.2004E+02
 3.8000E-02 -1.8600E+04   4.7820E-04   1.3240E+01              9.0000E-02 -1.5000E+00   6.5010E+00   4.2654E+02
 4.0000E-02 -1.5030E+04   6.9160E-04   1.5717E+01              9.2000E-02 -9.0000E-01   7.0150E+00   4.3075E+02
 4.2000E-02 -1.1580E+04   9.9970E-04   1.9164E+01              9.4000E-02 -5.0000E-01   7.5010E+00   4.3375E+02
 4.4000E-02 -8.9180E+03   2.8880E-03   2.6451E+01              9.6000E-02 -3.0000E-01   8.0140E+00   4.3550E+02
 4.6000E-02 -6.4680E+03   3.0190E-03   3.3043E+01              9.8000E-02 -1.0000E-01   8.5100E+00   4.3700E+02
 4.8000E-02 -5.2900E+03   4.3640E-03   3.9929E+01              1.0000E-01  0.0000E+00   9.0000E+00   4.3740E+02
 5.0000E-02 -4.0740E+03   6.3050E-03   4.7596E+01              1.0200E-01  1.0000E+00   9.0000E+00   4.4696E+02

   TIME END     SOIL FLUX     ET FLUX
 4.8000E+02  6.8000E-04  0.0000E+00
 7.2000E+02 -6.0200E-06 -1.0000E-05
 1.2000E+03  6.8000E-04 -1.0000E-05
 1.4400E+03 -2.0198E-06 -1.0000E-05
 1.9200E+03  6.8000E-04 -1.0000E-05
 2.1600E+03 -2.0000E-06 -1.0000E-05
 2.6400E+03  6.8000E-04 -1.0000E-05
 2.8800E+03 -2.0000E-06 -1.0000E-05
 3.3600E+03  6.8000E-04 -1.0000E-05
 3.6000E+03 -2.0000E-06 -1.0000E-05
 4.0800E+03  6.8000E-04 -1.0000E-05
 4.3200E+03 -2.0000E-06 -1.0000E-05
 4.8000E+03  6.8000E-04 -1.0000E-05
 5.0400E+03 -2.0000E-06 -1.0000E-05
 5.5200E+03  6.8000E-04 -1.0000E-05
 5.7600E+03 -2.0000E-06 -1.0000E-05
 6.2400E+03  6.8000E-04 -1.0000E-05
 6.4800E+03 -2.0000E-06 -1.0000E-05
 6.9600E+03  6.8000E-04 -1.0000E-05
 7.2000E+03 -2.0000E-06 -1.0000E-05
 7.6800E+03  6.8000E-04 -1.0000E-05
 7.9200E+03 -2.0000E-06 -1.0000E-05
 8.4000E+03  6.8000E-04 -1.0000E-05
 8.6400E+03 -2.0000E-06 -1.0000E-05
 9.1200E+03  6.8000E-04 -1.0000E-05
 9.3600E+03 -2.0000E-06 -1.0000E-05
 9.8400E+03  6.8000E-04 -1.0000E-05
 1.0080E+04 -2.0000E-06 -1.0000E-05
 1.0560E+04  6.8000E-04 -1.0000E-05
 1.0800E+04 -2.0000E-06 -1.0000E-05
 1.1280E+04  6.8000E-04 -1.0000E-05
 1.1520E+04 -2.0000E-06 -1.0000E-05
 1.2000E+04  6.8000E-04 -1.0000E-05
 1.2240E+04 -2.0000E-06 -1.0000E-05
 1.2720E+04  6.8000E-04 -1.0000E-05
 1.2960E+04 -2.0000E-06 -1.0000E-05
 1.3440E+04  6.8000E-04 -1.0000E-05
 1.3680E+04 -2.0000E-06 -1.0000E-05
 1.4160E+04  6.8000E-04 -1.0000E-05
 1.4400E+04 -2.0000E-06 -1.0000E-05
 1.4880E+04  6.8000E-04 -1.0000E-05
 1.5120E+04 -2.0000E-06 -1.0000E-05
 1.5600E+04  6.8000E-04 -1.0000E-05
 1.5840E+04 -2.0000E-06 -1.0000E-05
 1.6320E+04  6.8000E-04 -1.0000E-05
 1.6560E+04 -2.0000E-06 -1.0000E-05
 1.7040E+04  6.8000E-04 -1.0000E-05
 1.7280E+04 -2.0000E-06 -1.0000E-05
 1.7760E+04  6.8000E-04 -1.0000E-05
 1.8000E+04 -2.0000E-06 -1.0000E-05
 1.8480E+04  6.8000E-04 -1.0000E-05
 1.8720E+04 -2.0000E-06 -1.0000E-05
 1.9200E+04  6.8000E-04 -1.0000E-05
 1.9440E+04 -2.0000E-06 -1.0000E-05
 1.9920E+04  6.8000E-04 -1.0000E-05
 2.0160E+04 -2.0000E-06 -1.0000E-05
 2.0640E+04  6.8000E-04 -1.0000E-05
 2.0880E+04 -2.0000E-06 -1.0000E-05
 2.1360E+04  6.8000E-04 -1.0000E-05
 2.1600E+04 -2.0000E-06 -1.0000E-05
 2.2080E+04  6.8000E-04 -1.0000E-05
 2.2320E+04 -2.0000E-06 -1.0000E-05
 2.2800E+04  6.8000E-04 -1.0000E-05
 2.3040E+04 -2.0000E-06 -1.0000E-05
 2.3520E+04  6.8000E-04 -1.0000E-05
 2.3760E+04 -2.0000E-06 -1.0000E-05
 2.4240E+04  6.8000E-04 -1.0000E-05
 2.4480E+04 -2.0000E-06 -1.0000E-05
 2.4960E+04  6.8000E-04 -1.0000E-05
 2.5200E+04 -2.0000E-06 -1.0000E-05
 2.5680E+04  6.8000E-04 -1.0000E-05
 2.5920E+04 -2.0000E-06 -1.0000E-05
 2.6400E+04  6.8000E-04 -1.0000E-05
 2.6640E+04 -2.0000E-06 -1.0000E-05
 2.7120E+04  6.8000E-04 -1.0000E-05
 2.7360E+04 -2.0000E-06 -1.0000E-05
 2.7840E+04  6.8000E-04 -1.0000E-05
 2.8080E+04 -2.0000E-06 -1.0000E-05
 2.8560E+04  6.8000E-04 -1.0000E-05
 2.8800E+04 -2.0000E-06 -1.0000E-05
 2.9280E+04  6.8000E-04 -1.0000E-05
 2.9520E+04 -2.0000E-06 -1.0000E-05
```

```
3.0000E+04  6.8000E-04 -1.0000E-05
3.0240E+04 -2.0000E-06 -1.0000E-05
3.0720E+04  6.8000E-04 -1.0000E-05
3.0960E+04 -2.0000E-06 -1.0000E-05
3.1440E+04  6.8000E-04 -1.0000E-05
3.1680E+04 -2.0000E-06 -1.0000E-05
3.2160E+04  6.8000E-04 -1.0000E-05
3.2400E+04 -2.0000E-06 -1.0000E-05
3.2880E+04  6.8000E-04 -1.0000E-05
3.3120E+04 -2.0000E-06 -1.0000E-05
3.3600E+04  6.8000E-04 -1.0000E-05
3.3840E+04 -2.0000E-06 -1.0000E-05
3.4320E+04  6.8000E-04 -1.0000E-05
3.4560E+04 -2.0000E-06 -1.0000E-05
3.5040E+04  6.8000E-04 -1.0000E-05
3.5280E+04 -2.0000E-06 -1.0000E-05
3.5760E+04  6.8000E-04 -1.0000E-05
3.6000E+04 -2.0000E-06 -1.0000E-05
3.6480E+04  6.8000E-04 -1.0000E-05
3.6720E+04 -2.0000E-06 -1.0000E-05
3.7200E+04  6.8000E-04 -1.0000E-05
3.7440E+04 -2.0000E-06 -1.0000E-05
3.7920E+04  6.8000E-04 -1.0000E-05
3.8160E+04 -2.0000E-06 -1.0000E-05
3.8640E+04  6.8000E-04 -1.0000E-05
3.8880E+04 -2.0000E-06 -1.0000E-05
3.9360E+04  6.8000E-04 -1.0000E-05
3.9600E+04 -2.0000E-06 -1.0000E-05
4.0080E+04  6.8000E-04 -1.0000E-05
4.0320E+04 -2.0000E-06 -1.0000E-05
4.0800E+04  6.8000E-04 -1.0000E-05
4.1040E+04 -2.0000E-06 -1.0000E-05
4.1520E+04  6.8000E-04 -1.0000E-05
4.1760E+04 -2.0000E-06 -1.0000E-05
4.2240E+04  6.8000E-04 -1.0000E-05
4.2480E+04 -2.0000E-06 -1.0000E-05
4.2960E+04  6.8000E-04 -1.0000E-05
4.3200E+04 -2.0000E-06 -1.0000E-05
4.3680E+04  6.8000E-04 -1.0000E-05
4.3920E+04 -2.0000E-06 -1.0000E-05
4.4400E+04  6.8000E-04 -1.0000E-05
4.4640E+04 -2.0000E-06 -1.0000E-05
4.5120E+04  6.8000E-04 -1.0000E-05
4.5360E+04 -2.0000E-06 -1.0000E-05
4.5840E+04  6.8000E-04 -1.0000E-05
4.6080E+04 -2.0000E-06 -1.0000E-05
4.6560E+04  6.8000E-04 -1.0000E-05
4.6800E+04 -2.0000E-06 -1.0000E-05
4.7280E+04  6.8000E-04 -1.0000E-05
4.7520E+04 -2.0000E-06 -1.0000E-05
4.8000E+04  6.8000E-04 -1.0000E-05
4.8240E+04 -2.0000E-06 -1.0000E-05
4.8720E+04  6.8000E-04 -1.0000E-05
4.8960E+04 -2.0000E-06 -1.0000E-05
4.9440E+04  6.8000E-04 -1.0000E-05
4.9680E+04 -2.0000E-06 -1.0000E-05
5.0160E+04  6.8000E-04 -1.0000E-05
5.0400E+04 -2.0000E-06 -1.0000E-05
5.0880E+04  6.8000E-04 -1.0000E-05
5.1120E+04 -2.0000E-06 -1.0000E-05
```

```
5.1[illegible]E+04   6.[illegible]E-0[illegible]  -1.0000E-05
5.1[illegible]E+04  -2.0000E-05  -1.0000E-05
5.2320E+04   6.[illegible]E-0[illegible]  -1.0000E-05
5.2560E+04  -2.0000E-05  -1.0000E-05
5.3040E+04   6.0000E-04  -1.0000E-05
5.3280E+04  -2.0000E-06  -1.0000E-05
5.3760E+04   6.0000E-04  -1.0000E-05
5.4000E+04  -2.0000E-06  -1.0000E-05
5.4480E+04   6.9000E-04  -1.0000E-05
5.4720E+04  -2.0000E-05  -1.0000E-05
5.5200E+04   6.8000E-04  -1.0000E-05
5.5440E+04  -2.0000E-06  -1.0000E-05
5.5920E+04   6.4000E-04  -1.0000E-05
5.6160E+04  -2.0000E-05  -1.0000E-05
5.6640E+04   6.6000E-04  -1.0000E-05
5.6880E+04  -2.9000E-06  -1.0000E-05
5.7360E+04   6.8000E-04  -1.0000E-05
5.7600E+04  -2.0000E-06  -1.0000E-05
5.8080E+04   6.8000E-04  -1.0000E-05
5.8320E+04  -2.0000E-06  -1.0000E-05
5.8800E+04   6.0000E-04  -1.0000E-05
5.9040E+04  -2.0000E-06  -1.0000E-05
5.9520E+04   6.8000E-04  -1.0000E-05
5.9760E+04  -2.0000E-06  -1.0000E-05
6.0240E+04   6.8000E-04  -1.0000E-05
6.0480E+04  -2.0000E-06  -1.0000E-05
6.0960E+04   6.4000E-04  -1.0000E-05
6.1200E+04  -2.0000E-06  -1.0000E-05
6.1680E+04   6.9000E-04  -1.0000E-05
6.1920E+04  -2.0000E-05  -1.0000E-05
6.2400E+04   6.4000E-04  -1.0000E-05
6.2640E+04  -2.0000E-06  -1.0000E-05
6.3120E+04   6.4000E-04  -1.0000E-05
6.3360E+04  -2.0000E-06  -1.0000E-05
6.3840E+04   6.8000E-04  -1.0000E-05
6.4080E+04  -2.0000E-06  -1.0000E-05
6.4560E+04   6.8000E-04  -1.0000E-05
6.4800E+04  -2.0000E-05  -1.0000E-05
6.5280E+04   6.4000E-04  -1.0000E-05
6.5520E+04  -2.0000E-05  -1.0000E-05
6.6000E+04   6.8000E-04  -1.0000E-05
6.6240E+04  -2.0000E-05  -1.0000E-05
6.6720E+04   6.4000E-04  -1.0000E-05
6.6960E+04  -2.0000E-05  -1.0000E-05
6.7440E+04   6.8000E-04  -1.0000E-05
6.7680E+04  -2.0000E-06  -1.0000E-05
6.8160E+04   6.8000E-04  -1.0000E-05
6.8400E+04  -2.0000E-05  -1.0000E-05
6.8880E+04   6.8000E-04  -1.0000E-05
6.9120E+04  -2.0000E-05  -1.0000E-05
6.9600E+04   6.8000E-04  -1.0000E-05
6.9840E+04  -2.0000E-05  -1.0000E-05
7.0320E+04   6.8000E-04  -1.0000E-05
7.0560E+04  -2.0000E-06  -1.0000E-05
7.1040E+04   6.8000E-04  -1.0000E-05
7.1280E+04  -2.0000E-06  -1.0000E-05
7.1760E+04   6.8000E-04  -1.0000E-05
7.2000E+04  -2.0000E-05  -1.0000E-05
7.2480E+04   6.0000E-04  -1.0000E-05
7.2720E+04  -2.0000E-05  -1.0000E-05
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Moore Business Forms Inc

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7.3200E+04  6.8000E-04 -1.0000E-05
7.3440E+04 -2.0000E-06 -1.0000E-05
7.3920E+04  6.8000E-04 -1.0000E-05
7.4160E+04 -2.0000E-06 -1.0000E-05
7.4640E+04  6.8000E-04 -1.0000E-05
7.4880E+04 -2.0000E-06 -1.0000E-05
7.5360E+04  6.8000E-04 -1.0000E-05
7.5600E+04 -2.0000E-06 -1.0000E-05
7.6080E+04  6.8000E-04 -1.0000E-05
7.6320E+04 -2.0000E-06 -1.0000E-05
7.6800E+04  6.8000E-04 -1.0000E-05
7.7040E+04 -2.0000E-06 -1.0000E-05
7.7520E+04  6.8000E-04 -1.0000E-05
7.7760E+04 -2.0000E-06 -1.0000E-05
7.8240E+04  6.8000E-04 -1.0000E-05
7.8480E+04 -2.0000E-06 -1.0000E-05
7.8960E+04  6.8000E-04 -1.0000E-05
7.9200E+04 -2.0000E-06 -1.0000E-05
7.9680E+04  6.8000E-04 -1.0000E-05
7.9920E+04 -2.0000E-06 -1.0000E-05
8.0400E+04  6.8000E-04 -1.0000E-05
8.0640E+04 -2.0000E-06 -1.0000E-05
8.1120E+04  6.8000E-04 -1.0000E-05
8.1360E+04 -2.0000E-06 -1.0000E-05
8.1840E+04  6.8000E-04 -1.0000E-05
8.2080E+04 -2.0000E-06 -1.0000E-05
8.2560E+04  6.8000E-04 -1.0000E-05
8.2800E+04 -2.0000E-06 -1.0000E-05
8.3280E+04  6.8000E-04 -1.0000E-05
8.3520E+04 -2.0000E-06 -1.0000E-05
8.4000E+04  6.8000E-04 -1.0000E-05
8.4240E+04 -2.0000E-06 -1.0000E-05
8.4720E+04  6.8000E-04 -1.0000E-05
8.4960E+04 -2.0000E-06 -1.0000E-05
8.5440E+04  6.8000E-04 -1.0000E-05
8.5680E+04 -2.0000E-06 -1.0000E-05
8.6160E+04  6.8000E-04 -1.0000E-05
8.6400E+04 -2.0000E-06 -1.0000E-05
8.6880E+04  6.8000E-04 -1.0000E-05
8.7120E+04 -2.0000E-06 -1.0000E-05
8.7600E+04  6.8000E-04 -1.0000E-05
8.7600E+04 -2.0000E-06 -1.0000E-05
8.7600E+04  6.8000E-04 -1.0000E-05
8.7600E+04 -2.0000E-06 -1.0000E-05

    DETT         COND          TT          CUMT
 1.0000E+02  1.0000E-01  1.0000E+00  8.7600E+04

    HHPY         HHFT         WATL         WATH         DELW
-6.0000E+05  0.0000E+00  4.0000E-03  1.0000E-01  2.0000E-03

   ESTART       ESTOP         ANI
 1.0000E-01  6.0000E+01  8.0000E-01

   THESE ARE THE FLUXES IN EACH LAYER IN ORDER
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
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   TIME IS 0.1000E+03

      DD         WTSOLD        VOLWAT        HNCLD          FAM           RAS           P             Q             H             U
     (FT)          GM            ML            CI            CI            CI
  0.0000E+00   1.2035E+04   3.5344E+02   0.0000E+00   0.0000E+00   0.0000E+00   4.9927E-02   6.3050E-03  -4.1185E+03   6.8000E-02
  5.0000E-01   2.4069E+04   7.0690E+02   3.6000E-04   3.6000E-04   2.1445E-09   4.9924E-02   6.3050E-03  -4.1181E+03   5.4998E+01
  1.0000E+00   1.0831E+05   3.1811E+03   5.4467E-09   2.1005E-09   7.3022E-09   4.9928E-02   6.3050E-03  -4.1176E+03  -5.6248E-01
  5.0000E+00   2.1603E+05   6.3629E+03   4.1670E-08   4.4664E-09   3.2230E-08   4.9938E-02   6.3050E-03  -4.1140E+03  -5.6225E-01
  1.0000E+01   2.4069E+05   7.0710E+03   2.0267E-07   4.1675E-08   1.0099E-07   4.9941E-02   6.3050E-03  -4.1046E+03  -5.6195E-01
  1.5000E+01   2.4069E+05   7.0720E+03   7.5350E-06   2.0266E-07   7.5320E-06   4.9949E-02   6.3050E-03  -4.1051E+03  -5.6167E-01
  2.0000E+01   5.6104E+05   1.6610E+04   4.4911E-03   7.5350E-06   4.4836E-03   4.9955E-02   6.3050E-03  -4.1007E+03  -5.6149E-01
  3.0000E+01   3.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9971E-02   6.3050E-03  -4.0916E+03  -5.6107E-01
  4.0010E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9965E-02   6.3050E-03  -4.0829E+03  -5.6078E-01
  5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   6.3050E-03  -4.0740E+03   6.9871E-02
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     THE TIME IS  4.8000E+02 HOURS, WHICH IS        0 YEAR(S),  0 MONTH(S), AND  20 DAY(S) FROM THE BEGINNING.

DELT  IS 5.0000E+00 AND  DETT  IS 1.0000E+02

NORMAL RAIN

   SOIL        CUM RAIN     WATER IN    CUM EVAPO-    CUM WATER  * BALANCE
   FLUX        AND FLOOD     COLUMN       TRANS      OFF BOTTOM  % OF CUMS
 6.5000E-04   3.2640E-01   2.2356E+03  0.0000E+00   3.2848E-01 -1.9941E-03

   DD          WTSOLD        VOLWAT       WNCLD         PAW          RAS          W            B            H            U
  (FT)           GM            ML           CI           CI           CI
0.0000E+00   1.2035E+04   3.5343E+02   3.5992E-04   3.5991E-04   1.0298E-08   4.9925E-02   6.3049E-03 -4.1198E+03   3.4000E-03
5.0000E-01   2.4069E+04   7.0687E+02   2.1609E-08   4.9054E-09   1.0703E-08   4.9926E-02   6.3056E-03 -4.1192E+03  -2.8124E-02
1.0000E+00   1.0931E+05   3.1810E+03   6.9720E-08   1.5826E-08   5.5894E-08   4.9926E-02   6.3049E-03 -4.1187E+03  -2.8124E-02
5.0000E+00   2.1603E+05   6.3627E+03   2.0920E-07   4.7111E-08   1.6115E-07   4.9932E-02   6.3050E-03 -4.1152E+03  -2.8125E-02
1.0000E+01   2.4069E+05   7.0707E+03   6.6392E-07   1.2381E-07   5.4011E-07   4.9940E-02   6.3050E-03 -4.1107E+03  -2.8124E-02
1.5000E+01   2.4069E+05   7.0717E+03   3.1777E-05   3.2655E-07   3.1951E-05   4.9947E-02   6.3050E-03 -4.1062E+03  -2.8125E-02
2.0000E+01   3.6104E+05   1.0609E+04   1.9248E-02   1.2725E-05   1.9235E-02   4.9954E-02   6.3050E-03 -4.1018E+03  -2.8125E-02
3.0000E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9960E-02   6.3050E-03 -4.0924E+03  -2.8125E-02
4.0000E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9960E-02   9.5600E-02 -4.0839E+03  -2.2728E-01
5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   9.5400E-02 -4.0740E+03   3.3474E-03

NUCLIDE         HALF         DECAY       ORIGINAL     REMAINING      ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
 NAME           LIFE         FACTOR       AMOUNT     ON SURFACE   COL-AND DEC    COLUMN       BOTTOM
H3           1.0821E+05   9.9496E-01   3.6000E-04   0.0000E+00   3.6000E-04   3.5491E-04   0.0000E+00   2.0000E+04   0.0000E+00
C14          5.0171E+07   9.9999E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1400E-05   0.0000E+00   2.2000E+04   1.0000E+02
S35          2.1079E+03   8.5539E-01   2.5800E-06   0.0000E+00   2.5800E-06   2.2063E-06   0.0000E+00   9.1000E+02   1.0000E+02
CR51         6.6492E+02   6.0947E-01   1.2900E-03   0.0000E+00   1.2900E-03   7.8621E-04   0.0000E+00   5.3000E+09   1.0000E+01
MN54         7.7137E+03   9.5821E-01   7.5000E-04   0.0000E+00   7.5000E-04   7.1866E-04   0.0000E+00   6.6000E+07   1.0000E+01
FE55         2.3621E+04   9.8616E-01   1.2900E-03   0.0000E+00   1.2900E-03   1.2721E-03   0.0000E+00   3.5000E+03   1.5000E+02
CO58         1.7101E+03   8.2087E-01   1.2900E-03   0.0000E+00   1.2900E-03   1.0641E-03   0.0000E+00   4.0000E+04   1.0000E+02
CO60         4.5990E+04   9.9287E-01   3.9000E-03   0.0000E+00   3.9000E-03   3.8722E-03   0.0000E+00   1.7000E+03   1.0000E+02
NI59         7.0100E+08   1.0000E+00   3.9000E-05   0.0000E+00   3.9000E-05   3.9000E-05   0.0000E+00   1.1000E-01   1.0000E+02
NI63         8.0620E+05   9.9959E-01   7.2000E-03   0.0000E+00   7.2000E-03   7.1971E-03   0.0000E+00   8.2000E+01   1.0000E+02
ZN65         5.8372E+03   9.4516E-01   6.0000E-05   0.0000E+00   6.0000E-05   5.6709E-05   0.0000E+00   7.0000E+07   1.0000E+02
SR90         2.4982E+05   9.9868E-01   1.4400E-05   0.0000E+00   1.4400E-05   1.4381E-05   0.0000E+00   2.1000E+02   2.0000E+00
NB94         3.0355E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+03   1.0000E+02
ZR95         1.5727E+03   6.1111E-01   6.0000E-05   0.0000E+00   6.0000E-05   4.8667E-05   0.0000E+00   1.8000E+04   1.0000E+02
TC99         1.6565E+09   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.4000E+02   1.0000E-01
RU106        8.8494E+03   9.6348E-01   6.0000E-05   0.0000E+00   6.0000E-05   5.7809E-05   0.0000E+00   1.9000E+04   3.0000E+02
SB124        1.4454E+03   7.9629E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.1944E-05   0.0000E+00   5.1000E+04   3.0000E+00
SB125        2.4283E+04   9.8653E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.4794E-05   0.0000E+00   3.0000E+03   3.0000E+09
I125         1.4385E+03   7.0543E-01   4.5000E-06   0.0000E+00   4.5000E-06   3.5740E-06   0.0000E+00   7.6000E+06   1.0000E-01
I129         1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9200E-08   0.0000E+00   7.2000E-02   1.0000E-01
CS134        1.7961E+04   9.6188E-01   1.4400E-03   0.0000E+00   1.4400E-03   1.4138E-03   0.0000E+00   1.9000E+03   2.0000E+19
CS135        2.0394E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-03   2.0000E+01
CS137        2.6280E+05   9.9875E-01   2.5800E-03   0.0000E+00   2.5800E-03   2.5768E-03   0.0000E+00   1.3000E+02   2.0000E+01
CE144        6.8133E+03   9.5283E-01   6.0000E-05   0.0000E+00   6.0000E-05   5.7170E-05   0.0000E+00   1.0000E+06   1.0000E+02
EU152        1.1792E+05   9.9720E-01   1.4400E-07   0.0000E+00   1.4400E-07   1.4360E-07   0.0000E+00   6.5000E-03   1.2000E+03
EU154        7.4607E+04   9.9554E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.4336E-06   0.0000E+00   1.0000E-02   1.2000E+03
EU155        4.3362E+04   9.9234E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.4291E-06   0.0000E+00   1.8000E-02   1.2000E+03
RA226        1.4053E+07   9.9998E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4499E-07   0.0000E+00   5.6000E+02   5.0000E+01
TH230        7.0100E+08   1.0000E+00   2.1300E-07   0.0000E+00   2.1300E-07   2.1300E-07   0.0000E+00   2.3000E-02   1.2000E+03
TH232        1.2304E+14   1.0000E+00   2.5200E-08   2.5199E-08   1.1525E-12   1.1525E-12   0.0000E+00   1.2000E-07   1.2000E+03
U235         6.2200E+12   1.0000E+00   9.6000E-08   9.5534E-08   4.6047E-10   4.6047E-10   0.0000E+00   2.4000E-08   2.0000E+00
U238         3.9420E+13   1.0000E+00   2.1300E-06   2.1300E-06   1.1554E-11   1.1554E-11   0.0000E+00   3.8000E-07   2.0000E+00
NP237        1.8737E+10   1.0000E+00   1.3400E-10   0.0000E+00   1.3400E-10   1.3400E-10   0.0000E+00   8.0000E-04   7.0000E+01
PU239        7.5412E+05   9.9456E-01   9.6000E-07   0.0000E+00   9.6000E-07   9.5958E-07   0.0000E+00   6.3000E-09   2.0000E+02
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PU239     2.1100E+08  1.0000E+00  1.2900E-07  1.2811E-07  5.4738E-10  5.4738E-10  0.0000E+00  2.2900E-05  2.0000E+02
PU240     5.7816E+07  9.9999E-01  2.0100E-07  1.9549E-07  5.5137E-09  5.5137E-09  0.0000E+00  6.5900E-05  2.0000E+02
PU241     1.1563E+05  9.9718E-01  4.4500E-05  0.0000E+00  4.4500E-05  4.4350E-05  0.0000E+00  4.1900E-05  2.0000E+02
PU242     4.7801E+09  1.0000E+00  7.2300E-10  7.1843E-10  1.5687E-12  1.5687E-12  0.0000E+00  1.4000E-07  2.0000E+02
AM241     3.7942E+06  9.9941E-01  4.6900E-08  0.0000E+00  4.0000E-08  6.9942E-08  0.0000E+00  4.1000E-05  7.0000E+01
AM242     1.6018E+01  0.0000E+00  4.8100E-09  0.0000E+00  4.8000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
AM243     6.9648E+07  1.0000E+00  6.3000E-09  0.0000E+00  6.3000E-09  6.3000E-09  0.0000E+00  7.1000E-02  7.0000E+01
CM242     3.4100E+03  4.1937E-01  7.5300E-06  0.0000E+00  7.5000E-06  3.4954E-06  0.0000E+00  4.0000E-02  7.0000E+01
CM243     2.0280E+05  9.9875E-01  1.6100E-09  0.0000E+00  1.3000E-09  1.7977E-09  0.0000E+00  6.2000E-04  7.0000E+01
CM244     1.5046E+05  9.9790E-01  5.7900E-07  0.0000E+00  5.7900E-07  5.6843E-07  0.0000E+00  9.7000E-04  7.0000E+01

    DD         H3          C14         S35         CA41        MN54        FE55        CO58        CO60        NI59        NI63
   (FT)      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  2.8972E-02  0.0000E+00  0.0000E+00  1.8317E-15  1.6770E-15  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E-01  0.0000E+00  0.0000E+00  0.0000E+00  1.6980E-13  1.5521E-13  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  8.4037E-12  7.6817E-12  1.0594E-16  1.1549E-15  1.5240E-15  0.0000E+00  2.6633E-15
5.0000E+00  0.0000E+00  1.3869E-11  2.0959E-15  9.4110E-10  8.6024E-10  3.0760E-13  1.2995E-12  2.0158E-12  5.2114E-15  3.5673E-12
1.0000E+01  0.0000E+00  2.5172E-11  4.4731E-12  1.7128E-07  1.5656E-07  4.0845E-10  2.3496E-09  4.5031E-09  1.5601E-11  8.1001E-09
1.5000E+01  0.0000E+00  4.1528E-09  8.0340E-09  2.0330E-05  2.5896E-05  2.5318E-06  3.0761E-06  9.6748E-06  5.0409E-08  1.7696E-05
2.0000E+01  0.0000E+00  3.0646E-05  5.4320E-06  2.0965E-03  1.9163E-03  3.4213E-03  2.0605E-02  1.0412E-02  1.0490E-04  1.9353E-02

    DD         ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
   (FT)      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  0.0000E+00  1.8822E-13  0.0000E+00  0.0000E+00  2.8435E-08  0.0000E+00  3.0148E-14  0.0000E+00  1.0453E-06  2.0078E-09
5.0000E-01  0.0000E+00  3.4954E-12  0.0000E+00  0.0000E+00  2.2737E-08  0.0000E+00  1.1904E-12  0.0000E+00  8.4775E-07  1.6545E-09
1.0000E+00  5.0030E-17  3.8643E-11  0.0000E+00  4.9800E-17  1.0294E-08  0.0000E+00  1.5903E-11  0.0000E+00  6.0751E-07  1.4309E-09
5.0000E+00  6.6088E-14  9.9653E-10  0.0000E+00  5.9204E-14  2.4237E-08  2.0082E-15  5.0740E-10  0.0000E+00  9.0364E-07  2.5544E-09
1.0000E+01  1.2522E-10  4.3255E-08  0.0000E+00  1.0788E-10  5.7061E-08  1.4147E-11  2.7923E-08  0.0000E+00  2.1276E-06  7.5235E-09
1.5000E+01  2.0657E-07  1.8025E-06  0.0000E+00  1.7728E-07  1.2174E-07  7.0249E-08  1.3959E-06  1.7940E-15  4.5349E-06  2.1259E-08
2.0000E+01  1.5245E-04  3.7663E-05  0.0000E+00  1.3083E-04  1.1722E-07  1.5550E-04  3.1140E-05  3.9817E-05  4.3708E-06  3.0334E-08

    DD         CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
   (FT)      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
5.0000E-01  0.0000E+00  0.0000E+00  5.1969E-15  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  0.0000E+00  5.9169E-13  5.8501E-17  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E+00  0.0000E+00  1.5324E-15  1.5475E-10  6.9508E-14  0.0000E+00  0.0000E+00  0.0000E+00  3.3524E-15  0.0000E+00  0.0000E+00
1.0000E+01  0.0000E+00  9.3590E-13  7.2171E-08  1.2624E-10  4.0025E-16  3.9148E-15  3.9585E-15  3.0426E-12  7.1247E-16  0.0000E+00
1.5000E+01  0.0000E+00  6.1096E-10  3.1567E-05  2.0825E-07  1.5864E-11  1.5281E-10  1.5342E-10  2.5103E-09  2.5234E-11  8.5505E-19
2.0000E+01  3.8042E-03  2.5790E-07  6.4122E-03  1.5369E-04  3.8637E-07  3.8578E-06  3.8852E-06  9.2659E-07  5.7310E-07  3.1011E-12
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     THE TIME IS  7.2000E+02 HOURS,  WHICH IS        0 YEAR(S),  1 MONTH(S), AND   0 DAY(S) FROM THE BEGINNING.

 DELT  IS 2.5000E+00 AND  DETI  IS 5.0000E+01

 DRY PERIOD

    SOIL       CUM RAIN     WATER IN    CUM EVAPO-    CUM WATER     BALANCE
    FLUX       AND FLOOD     COLUMN       TRANS      OFF BOTTOM   % OF CUMS
 -6.0230E-05  3.2800E-01  2.2355E+00 -1.4141E-03  3.2735E-01 -3.5810E-08

     DD          WTSOLD       VOLWAT       WNCLD          RAM          RAS            K            D            H            W
    (FT)           GM           ML           CI            CI           CI
  0.0000E+00  1.2035E+04  3.5317E+02  3.5943E-04  3.5837E-04  6.5819E-08  4.9888E-02  6.3050E-03 -4.1240E+03 -1.5050E-05
  5.0000E-01  2.4069E+04  7.0677E+02  1.0385E-07  2.0253E-08  8.2597E-08  4.9914E-02  6.3045E-03 -4.1235E+03 -1.5651E-02
  1.0000E+00  1.0831E+05  3.1805E+03  2.3724E-07  5.3834E-08  1.8340E-07  4.9914E-02  6.3050E-03 -4.1230E+03 -1.5775E-02
  5.0000E+00  2.1603E+05  6.3419E+03  4.0189E-07  1.0549E-07  3.6340E-07  4.9926E-02  6.3050E-03 -4.1190E+03 -1.5777E-02
  1.0000E+01  2.4069E+05  7.0649E+03  1.1600E-06  1.7307E-07  9.8697E-07  4.9931E-02  6.3049E-03 -4.1140E+03 -1.5777E-02
  1.5000E+01  2.4069E+05  7.0711E+03  6.3181E-05  3.3060E-07  6.2950E-05  4.9942E-02  6.3050E-03 -4.1090E+03 -1.5777E-02
  2.0000E+01  3.0108E+05  1.0808E+04  1.8874E-02  1.1841E-05  1.8862E-02  4.9951E-02  6.3050E-03 -4.1000E+03 -1.5777E-02
  3.0000E+01  4.8139E+05  1.4139E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9967E-02  6.3050E-03 -4.0940E+03 -1.5777E-02
  4.0000E+01  4.8139E+05  1.4158E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9984E-02  9.5549E-02 -4.0840E+03 -1.2749E-01
  5.0000E+01  2.4069E+05  1.4159E+04  0.0000E+00  0.0000E+00  0.0000E+00  1.0000E-01  9.5549E-02 -4.0740E+03 -1.4587E-05

 NUCLIDE         HALF        DECAY       ORIGINAL     REMAINING     ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
  NAME           LIFE        FACTOR       AMOUNT     ON SURFACE   COL-NO DEC    COLUMN       BOTTOM
 H3           1.0821E+05  9.9541E-01  3.6000E-04  0.0000E+00  3.6000E-04  3.5835E-04  0.0000E+00  2.6000E+04  0.0000E+00
 C14          5.0171E+07  9.9999E-01  1.1000E-05  0.0000E+00  1.1000E-05  1.1000E-05  0.0000E+00  2.2000E+04  1.0000E+02
 S35          2.1079E+03  7.8083E-01  2.5800E-06  0.0000E+00  2.5800E-06  2.0378E-06  0.0000E+00  4.1000E+02  1.0000E+02
 CR51         6.6492E+02  4.7333E-01  1.2900E-03  0.0000E+00  1.2900E-03  6.1059E-04  0.0000E+00  5.3000E+04  1.0000E+01
 MN54         7.7137E+03  9.3756E-01  7.5000E-04  0.0000E+00  7.5000E-04  7.0317E-04  0.0000E+00  6.6000E+07  1.0000E+01
 FE55         2.3621E+04  9.7917E-01  1.2900E-03  0.0000E+00  1.2900E-03  1.2631E-03  0.0000E+00  3.5000E+03  1.5000E+02
 CO58         1.7101E+03  7.4750E-01  1.2900E-03  0.0000E+00  1.2900E-03  9.6445E-04  0.0000E+00  4.8000E+04  1.0000E+02
 CO60         4.5990E+04  9.8924E-01  3.9000E-03  0.0000E+00  3.9000E-03  3.8581E-03  0.0000E+00  1.7000E+03  1.0000E+02
 NI59         7.0100E+08  1.0000E+00  3.9000E-05  0.0000E+00  3.9000E-05  3.9000E-05  0.0000E+00  1.1000E-01  1.0000E+02
 NI63         8.0620E+05  9.9938E-01  7.2000E-03  0.0000E+00  7.2000E-03  7.1956E-03  0.0000E+00  8.2000E+01  1.0000E+02
 ZN65         5.8372E+03  9.1833E-01  6.0000E-05  0.0000E+00  6.0000E-05  5.5100E-05  0.0000E+00  7.0000E+07  1.0000E+02
 SR90         2.4982E+05  9.9801E-01  1.4400E-05  0.0000E+00  1.4400E-05  1.4371E-05  0.0000E+00  2.1000E+02  2.0000E+00
 NB93         3.0353E-01  0.0000E+00  4.2000E-07  0.0000E+00  4.2000E-07  0.0000E+00  0.0000E+00  1.6000E+03  1.0000E+02
 ZR95         1.5727E+03  7.2889E-01  6.0000E-05  0.0000E+00  6.0000E-05  4.3734E-05  0.0000E+00  1.8000E+08  1.0000E+02
 TC99         1.8565E+09  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  1.4000E+02  1.0000E-01
 RU106        8.8894E+03  9.4535E-01  6.0000E-05  0.0000E+00  6.0000E-05  5.6721E-05  0.0000E+00  1.9000E+04  3.0000E+02
 SB124        1.4454E+03  7.0867E-01  1.5000E-05  0.0000E+00  1.5000E-05  1.0633E-05  0.0000E+00  5.1000E+04  3.0000E+09
 SB125        2.4283E+04  9.7973E-01  1.5000E-05  0.0000E+00  1.5000E-05  1.4694E-05  0.0000E+00  3.0000E+03  3.0000E+09
 I125         1.4385E+03  7.0771E-01  4.5000E-06  0.0000E+00  4.5000E-06  3.1847E-06  0.0000E+00  7.6000E+06  1.0000E-01
 I129         1.4916E+11  1.0000E+00  1.4200E-08  0.0000E+00  1.4200E-08  1.4200E-08  0.0000E+00  7.2000E-02  1.0000E-01
 CS134        1.7601E+04  9.7209E-01  1.4400E-03  0.0000E+00  1.4400E-03  1.4007E-03  0.0000E+00  1.9000E+03  2.0000E+19
 CS135        2.6394E+10  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  1.7000E-03  2.0000E+01
 CS137        2.6200E+05  9.9811E-01  2.5800E-03  0.0000E+00  2.5800E-03  2.5751E-03  0.0000E+00  1.3000E+02  2.0000E+01
 CE144        6.8133E+03  9.2861E-01  6.0000E-05  0.0000E+00  6.0000E-05  5.5776E-05  0.0000E+00  1.8000E+06  1.0000E+02
 EU152        1.1742E+05  9.9577E-01  1.4400E-07  0.0000E+00  1.4400E-07  1.4339E-07  0.0000E+00  6.5000E-03  1.2000E+03
 EU154        7.0887E+04  9.9335E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.4304E-06  0.0000E+00  1.0000E-02  1.2000E+03
 EU155        4.3362E+04  9.8860E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.4236E-06  0.0000E+00  1.8000E-02  1.2000E+03
 RA226        1.4053E+07  9.9996E-01  3.4500E-07  0.0000E+00  3.4500E-07  3.4494E-07  0.0000E+00  5.6000E+02  5.0000E+01
 TH230        7.0100E+09  1.0000E+00  2.1300E-07  0.0000E+00  2.1300E-07  2.1300E-07  0.0000E+00  2.3000E-02  1.2000E+03
 TH232        1.2380E+14  1.0000E+00  2.5200E-08  0.0000E+00  2.5200E-08  2.5200E-08  0.0000E+00  1.2000E-07  1.2000E+03
 U235         6.2200E+12  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  2.0000E-06  2.0000E+09
 U238         3.9420E+13  1.0000E+00  2.1300E-06  1.8292E-06  3.0083E-07  3.0083E-07  0.0000E+00  3.0000E-07  2.0000E+09
 NP237        1.0737E+10  1.0000E+00  1.3800E-10  0.0000E+00  1.3800E-10  1.3800E-10  0.0000E+00  6.0000E-04  7.0000E+01
 PU238        7.5412E+05  9.9034E-01  9.6000E-07  0.0000E+00  9.6000E-07  9.5937E-07  0.0000E+00  8.3000E-03  2.0000E+02
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   PU239    2.1000E+01  1.0000E+00  1.2100E-07  0.0000E+00  1.2400E-07  1.2900E-07  0.0000E+00  2.2000E-06  2.0000E+02
   PU240    5.7010E+07  9.9999E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0100E-07  0.0000E+00  8.3000E-06  2.0000E+02
   PU241    1.1563E+05  9.9571E-01  4.9500E-05  0.0000E+00  4.9500E-05  4.9200E-05  0.0000E+00  4.1000E-03  2.0000E+02
   PU242    4.7701E+07  1.0000E+00  7.2100E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.4000E-07  2.0000E+02
   AM241    3.7942E+00  9.9987E-01  9.1000E-08  0.0000E+00  9.0000E-08  8.9900E-08  0.0000E+00  4.1000E-05  7.0000E+01
   AM242    1.6610E+01  0.0000E+00  4.8000E-09  0.0000E+00  4.8000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
   AM243    6.9640E+07  9.9999E-01  6.3100E-09  0.0000E+00  6.3000E-09  6.3000E-09  0.0000E+00  7.1000E-02  7.0000E+01
   CM242    3.9160E+05  8.8075E-01  7.5000E-06  0.0000E+00  7.5000E-06  6.6050E-06  0.0000E+00  4.0000E-02  7.0000E+01
   CM243    2.6200E+05  9.9811E-01  1.8000E-09  0.0000E+00  1.8000E-09  1.7900E-09  0.0000E+00  6.2000E-04  7.0000E+01
   CM244    1.5600E+05  9.9683E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.6817E-07  0.0000E+00  9.7000E-04  7.0000E+01

    DP          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  2.8927E-02  0.0000E+00  0.0000E+00  1.9258E-14  2.2178E-14  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E-01  0.0000E+00  0.0000E+00  0.0000E+00  1.8877E-12  1.7133E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  5.2394E-17
1.0000E+00  0.0000E+00  9.0020E-17  8.3319E-18  5.3372E-11  6.3969E-11  1.0807E-15  8.6624E-15  1.9753E-14  9.4223E-17  3.5945E-14
5.0000E+00  0.0000E+00  7.5703E-14  1.5547E-14  3.9620E-09  4.5427E-09  1.9687E-12  6.4114E-12  1.6325E-11  9.2391E-14  2.9824E-11
1.0000E+01  0.0000E+00  8.5091E-11  1.5210E-11  4.8867E-07  5.1370E-07  3.5232E-09  7.1962E-09  2.0808E-08  1.3938E-10  3.0274E-08
1.5000E+01  0.0000E+00  8.0398E-08  1.4371E-08  4.2262E-05  4.8676E-05  5.3884E-06  6.6017E-06  2.2808E-05  1.8355E-07  4.2248E-05
2.0000E+01  0.0000E+00  3.0620E-05  5.4734E-06  1.6145E-03  1.8592E-03  3.3951E-03  2.5905E-03  1.0366E-02  1.0081E-04  1.9333E-02

    DP          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  0.0000E+00  3.4022E-12  0.0000E+00  0.0000E+00  2.0050E-07  0.0000E+00  4.2725E-13  0.0000E+00  6.6515E-06  2.3419E-08
5.0000E-01  0.0000E+00  5.5237E-11  0.0000E+00  0.0000E+00  1.2572E-07  0.0000E+00  9.8523E-12  0.0000E+00  4.1708E-06  1.6051E-08
1.0000E+00  4.9148E-16  8.3547E-10  0.0000E+00  3.9009E-16  6.1984E-08  0.0000E+00  1.0700E-10  0.0000E+00  2.0562E-06  8.9281E-09
5.0000E+00  3.6628E-13  7.1776E-09  0.0000E+00  2.9073E-13  6.0673E-08  1.3992E-14  2.0007E-09  0.0000E+00  2.0128E-06  9.8154E-09
1.0000E+01  4.1128E-10  1.8206E-07  0.0000E+00  3.2689E-10  8.0676E-08  4.7117E-11  8.1655E-08  0.0000E+00  2.9417E-06  1.6406E-08
1.5000E+01  3.8859E-07  3.9689E-06  0.0000E+00  3.0843E-07  1.0955E-07  1.3358E-07  2.3370E-06  3.4620E-15  3.0342E-06  2.3685E-08
2.0000E+01  1.0808E-04  3.5897E-05  0.0000E+00  1.1747E-04  5.6094E-08  1.5253E-04  2.6946E-05  3.9542E-05  1.8604E-06  1.4516E-08

    DP          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  0.0000E+00  0.0000E+00  5.8000E-16  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E-01  0.0000E+00  0.0000E+00  4.9900E-14  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  1.4197E-16  7.4325E-12  4.9751E-16  0.0000E+00  0.0000E+00  0.0000E+00  3.5778E-17  0.0000E+00  0.0000E+00
5.0000E+00  0.0000E+00  2.7869E-14  1.3216E-09  3.7078E-13  0.0000E+00  0.0000E+00  0.0000E+00  1.8298E-14  0.0000E+00  0.0000E+00
1.0000E+01  0.0000E+00  8.3049E-12  3.3961E-07  4.1633E-10  3.5377E-15  3.5991E-14  3.5861E-14  1.0276E-11  5.5800E-15  9.6369E-17
1.5000E+01  0.0000E+00  2.2379E-09  7.5955E-05  3.4337E-07  5.6305E-11  5.6010E-10  5.5851E-10  4.8559E-09  8.5933E-11  2.9492E-12
2.0000E+01  3.7688E-03  2.5601E-07  6.0780E-03  1.4982E-08  3.8574E-07  3.8085E-06  3.8301E-06  9.2502E-07  5.7304E-07  6.7804E-08
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     THE TIME IS  3.6000E+03 HOURS, WHICH IS        0 YEAR(S),  5 MONTH(S), AND   0 DAY(S) FROM THE BEGINNING.

 DELT  IS 2.5000E+00 AND  DETT  IS 5.0000E+01

 DRY PERIOD

    SOIL        CUM RAIN     WATER IN    CUM EVAPO-    CUM WATER     BALANCE
    FLUX        AND FLOOD     COLUMN       TRANS      OFF BOTTOM    % OF CUMS
 -2.0000E-06   1.6320E+00   2.2355E+00 -3.3640E-03   1.6325E+00  -1.8192E-03

     DD          WTSOLD        VOLWAT       RNCLD         RAW           RAS           A             B            H            U
    (FT)           GM            ML           CI           CI            CI
 0.0000E+00   1.2035E+04   3.5332E+02   3.5249E-04   3.5196E-04   5.3292E-07   4.9910E-02   6.3050E-03 -4.1240E+03 -5.0000E-06
 5.0000E-01   2.4009E+04   7.0677E+02   1.5212E-07   3.4151E-08   1.1777E-07   4.9914E-02   6.3047E-03 -4.1235E+03 -1.5972E-02
 1.0000E+00   1.0831E+05   3.1005E+03   5.7986E-08   8.9265E-09   4.8959E-09   4.9919E-02   6.3050E-03 -4.1230E+03 -1.5766E-02
 5.0000E+00   2.1663E+05   6.3619E+03   2.7985E-07   7.2548E-09   2.7259E-07   4.9926E-02   6.3050E-03 -4.1190E+03 -1.5765E-02
 1.0000E+01   2.4069E+05   7.0649E+03   5.9748E-06   2.6353E-08   5.9484E-06   4.9934E-02   6.3050E-03 -4.1140E+03 -1.5765E-02
 1.5000E+01   2.4009E+05   7.0711E+03   2.5619E-04   3.8421E-07   2.5576E-04   4.9942E-02   6.3050E-03 -4.1090E+03 -1.5765E-02
 2.0000E+01   3.0104E+05   1.0608E+04   1.0733E-02   8.8476E-06   1.0724E-02   4.9951E-02   6.3050E-03 -4.1040E+03 -1.5765E-02
 3.0000E+01   4.8134E+05   1.4149E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9967E-02   6.3050E-03 -4.0940E+03 -1.5765E-02
 4.0000E+01   4.8139E+05   1.4154E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9984E-02   9.5594E-02 -4.0840E+03 -1.2748E-01
 5.0000E+01   2.4009E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   9.5597E-02 -4.0740E+03 -2.9178E-06

 NUCLIDE         HALF         DECAY       ORIGINAL     REMAINING     ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
  NAME           LIFE         FACTOR       AMOUNT     ON SURFACE.  COL-NO DEC     COLUMN       BOTTOM
 H3          1.0821E+05   9.7727E-01   3.6000E-04   0.0000E+00   3.6000E-04   3.5180E-04   0.0000E+00   2.6000E+04   0.0000E+00
 C14         5.0171E+07   9.9995E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1394E-05   0.0000E+00   2.2000E+04   1.0000E+02
 S35         2.1079E+03   3.0636E-01   2.5800E-06   0.0000E+00   2.5800E-06   7.9041E-07   0.0000E+00   9.1000E+02   1.0000E+02
 CR51        6.6492E+02   2.3512E-02   1.2900E-03   0.0000E+00   1.2900E-03   3.0330E-05   0.0000E+00   5.3000E+09   1.0000E+01
 MN54        7.7137E+03   7.2378E-01   7.5000E-04   0.0000E+00   7.5000E-04   5.4283E-04   0.0000E+00   6.6000E+07   1.0000E+01
 FE55        2.3621E+04   8.9982E-01   1.2900E-03   0.0000E+00   1.2900E-03   1.1604E-03   0.0000E+00   3.5000E+03   1.5000E+02
 CO58        1.7101E+03   2.3295E-01   1.2900E-03   0.0000E+00   1.2900E-03   3.0012E-04   0.0000E+00   4.8000E+09   1.0000E+02
 CO60        4.5990E+04   9.4722E-01   3.9000E-03   0.0000E+00   3.9000E-03   3.6942E-03   0.0000E+00   1.7000E+03   1.0000E+02
 NI59        7.0100E+08   1.0000E+00   3.9000E-05   0.0000E+00   3.9000E-05   3.9000E-05   0.0000E+00   1.1000E-01   1.0000E+02
 NI63        8.0620E+05   9.9641E-01   7.2000E-03   0.0000E+00   7.2000E-03   7.1779E-03   0.0000E+00   8.2000E+01   1.0000E+02
 ZN65        5.8372E+03   6.5230E-01   6.0000E-05   0.0000E+00   6.0000E-05   3.9140E-05   0.0000E+00   7.0000E+07   1.0000E+02
 SR90        2.4082E+05   9.9007E-01   1.4300E-05   0.0000E+00   1.4400E-05   1.4257E-05   0.0000E+00   2.1000E+02   2.0000E+00
 NB94        6.0354E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+03   1.0000E+02
 ZR95        1.5727E+03   2.0084E-01   6.0000E-05   0.0000E+00   6.0000E-05   1.2240E-05   0.0000E+00   1.8000E+04   1.0000E+02
 TC99        1.8565E+09   1.0000E+00   9.6100E-08   0.0000E+00   9.6000E-08   9.6100E-08   0.0000E+00   1.4000E+02   1.0000E-01
 RU106       8.8494E+03   7.5444E-01   6.0000E-05   0.0000E+00   6.0000E-05   4.5265E-05   0.0000E+00   1.9000E+08   3.0000E+02
 SB124       1.4450E+03   1.7814E-01   1.5000E-05   0.0000E+00   1.5000E-05   2.6721E-06   0.0000E+00   5.1000E+04   3.0000E+00
 SB125       2.4203E+04   9.0241E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.3535E-05   0.0000E+00   3.0000E+03   3.0000E+09
 I125        1.4385E+03   1.7658E-01   4.5000E-06   0.0000E+00   4.5000E-06   7.9500E-07   0.0000E+00   7.0000E+06   1.0000E-01
 I129        1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9201E-08   0.0000E+00   7.2000E-02   1.0000E-01
 CS134       1.7961E+04   8.7037E-01   1.4400E-03   0.0000E+00   1.4400E-03   1.2533E-03   0.0000E+00   1.9000E+03   2.0000E+19
 CS135       2.0340E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-03   2.0000E+01
 CS137       2.6288E+05   9.9756E-01   2.5900E-03   0.0000E+00   2.5900E-03   2.5556E-03   0.0000E+00   1.5000E+02   2.0000E+01
 CE144       6.8133E+03   6.9351E-01   6.0000E-05   0.0000E+00   6.1000E-05   4.1411E-05   0.0000E+00   1.8000E+06   1.0000E+02
 EU152       1.1712E+05   9.7890E-01   1.4400E-07   0.0000E+00   1.4400E-07   1.4097E-07   0.0000E+00   6.5000E-03   1.2000E+03
 EU154       7.4467E+04   9.6708E-01   1.4300E-06   0.0000E+00   1.4400E-06   1.3926E-06   0.0000E+00   1.0000E-02   1.2000E+03
 EU155       4.3362E+04   9.4412E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.3595E-06   0.0000E+00   1.8000E-02   1.2000E+03
 RA226       1.4053E+07   9.9982E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4494E-07   0.0000E+00   5.6000E+02   5.0000E+01
 TH230       7.0100E+09   1.0000E+00   2.1300E-07   0.0000E+00   2.1300E-07   2.1300E-07   0.0000E+00   2.3000E-02   1.2000E+03
 TH232       1.2306E+14   1.0000E+00   2.5200E-08   0.0000E+00   2.5200E-09   2.5200E-08   0.0000E+00   1.2000E-07   1.2000E+03
 U235        6.2201E+12   1.0000E+00   4.6000E-08   0.0000E+00   4.6000E-08   4.6000E-08   0.0000E+00   2.4000E-06   2.0000E+00
 U238        3.9420E+13   1.0000E+00   2.1300E-06   0.0000E+00   2.1300E-06   2.1300E-06   0.0000E+00   3.0000E-07   2.0000E+00
 NP237       1.8737E+10   1.0000E+00   1.3800E-10   0.0000E+00   1.3800E-10   1.3800E-10   0.0000E+00   8.0000E-04   7.0000E+01
 PU239       7.5912E+05   9.9670E-01   9.6000E-07   0.0000E+00   9.6000E-07   9.5683E-07   0.0000E+00   6.3000E-04   2.0000E+02
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PU239     2.4390E+04  9.9990E-01  1.2300E-07  0.0000E+00  1.2900E-07  1.2300E-07  0.0000E+00  2.2300E-05  2.0000E+02
PU240     6.7615E+07  9.9990E-01  2.1100E-07  0.0000E+00  2.1100E-07  2.0050E-07  0.0000E+00  8.3000E-05  2.0000E+02
PU241     1.1563E+05  9.7367E-01  4.9900E-05  0.0000E+00  4.7500E-05  3.4110E-05  0.0000E+00  4.1000E-05  2.0000E+02
PU242     4.7401E+03  1.0000E+00  7.2100E-10  0.0000E+00  7.2100E-10  7.2061E-10  0.0000E+00  1.4000E-07  2.0000E+02
AM241     5.7902E+00  9.9930E-01  9.0000E-08  0.0000E+00  9.0000E-08  8.9941E-09  0.0000E+00  4.1000E-05  7.0000E+01
AM242     1.6018E+01  0.0000E+00  4.8000E-09  0.0000E+00  4.8000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
AM243     6.3696E+07  9.9990E-01  6.5000E-09  0.0000E+00  6.5000E-09  6.2994E-09  0.0000E+00  7.1000E-02  7.0000E+01
CM242     3.9160E+03  5.2905E-01  7.5000E-06  0.0000E+00  7.5000E-06  3.9679E-06  0.0000E+00  4.0000E-02  7.0000E+01
CM243     2.6280E+05  9.9056E-01  1.9000E-09  0.0000E+00  1.9000E-09  1.7830E-09  0.0000E+00  6.2000E-04  7.0000E+01
CM244     1.5040E+05  9.8419E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.6193E-07  0.0000E+00  9.7000E-04  7.0000E+01

                                                                                                            NI59        NI63
   D           H3          C14         S35          CR51         MN54         FE55         CO58         CO60        MCI/GM      MCI/GM
  (FT)       MCI/GM      MCI/GM      MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM     0.0000E+00  2.4628E-16
0.0000E+00  2.8394E-02  0.0000E+00  0.0000E+00  2.9638E-12  5.3044E-11  0.0000E+00  0.0000E+00  0.0000E+00  5.8307E-16  1.7054E-13
5.0000E-01  0.0000E+00  4.9830E-17  0.0000E+00  7.6829E-11  1.3750E-09  3.8291E-15  8.3492E-15  8.8270E-14  8.7600E-14  1.8422E-11
1.0000E+00  0.0000E+00  3.3310E-14  2.3081E-15  8.0832E-10  1.3367E-09  6.2683E-13  4.7720E-13  9.5267E-12  1.8727E-11  3.8125E-09
5.0000E+00  0.0000E+00  6.6440E-12  4.6344E-13  1.6273E-08  2.4120E-07  1.4173E-10  1.7599E-10  1.9692E-09  5.5898E-09  1.1014E-06
1.0000E+01  0.0000E+00  1.8701E-09  1.2907E-10  4.5661E-07  8.1721E-06  8.1845E-08  4.9236E-08  5.6820E-07  1.2752E-06  2.4293E-04
1.5000E+01  0.0000E+00  3.4909E-07  2.7073E-08  9.7746E-06  1.7494E-04  2.6671E-05  1.0507E-05  1.2518E-04  1.0408E-04  1.9151E-02
2.0000E+01  0.0000E+00  3.0005E-05  2.1082E-06  7.4779E-05  1.3384E-03  3.1050E-03  8.0051E-04  9.8561E-03

                                                                                              I125        I129
   D          ZN65        SR90         Y90          ZR95         TC99         RU106        SB124        SB125       MCI/GM      MCI/GM
  (FT)       MCI/GM      MCI/GM      MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM     4.8568E-05  1.1475E-06
0.0000E+00  0.0000E+00  1.2808E-08  0.0000E+00  0.0000E+00  5.8643E-06  0.0000E+00  2.8642E-10  0.0000E+00  5.2980E-06  1.3035E-07
5.0000E-01  9.4029E-16  6.5315E-08  0.0000E+00  3.1096E-16  6.3971E-07  0.0000E+00  2.1734E-09  0.0000E+00  2.4833E-07  8.2551E-09
1.0000E+00  1.1440E-13  1.0330E-07  0.0000E+00  3.5922E-14  3.6022E-08  1.6254E-15  6.9285E-09  0.0000E+00  8.3259E-08  2.3721E-09
5.0000E+00  2.2951E-11  6.0131E-07  0.0000E+00  7.2067E-12  1.0053E-08  9.8958E-13  4.2218E-08  0.0000E+00  3.1070E-08  9.1327E-10
1.0000E+01  6.4211E-09  3.5127E-06  0.0000E+00  2.0163E-09  3.7516E-09  8.3039E-10  3.5810E-07  0.0000E+00  9.0043E-09  2.7314E-10
1.5000E+01  1.3703E-08  1.5681E-05  0.0000E+00  4.3028E-07  1.0872E-09  5.3151E-07  2.3182E-06  1.5943E-14  1.0334E-09  3.2305E-11
2.0000E+01  1.9848E-04  2.5157E-05  0.0000E+00  3.2761E-05  1.2488E-10  1.2144E-04  5.3780E-06  3.6422E-05

                                                                                              TH230       TH232
   D          CS134       CS135        CS137        CE144        EU152        EU154        EU155        RA226       MCI/GM      MCI/GM
  (FT)       MCI/GM      MCI/GM      MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM       MCI/GM     0.0000E+00  0.0000E+00
0.0000E+00  0.0000E+00  0.0000E+00  3.3941E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0010E-01  0.0000E+00  5.6833E-15  1.8207E-10  1.0528E-15  0.0000E+00  0.0000E+00  0.0000E+00  4.7740E-17  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  1.2089E-13  3.4345E-09  1.2162E-13  0.0000E+00  0.0000E+00  0.0000E+00  1.5950E-14  2.1912E-17  0.0000E+00
5.0000E+00  0.0000E+00  5.5439E-12  1.0331E-07  2.4400E-11  0.0000E+00  3.7425E-16  3.6564E-16  1.6022E-12  2.1542E-13  2.0571E-14
1.0000E+01  0.0000E+00  3.3158E-10  5.4175E-06  6.1264E-09  1.4147E-13  1.3963E-12  1.3659E-12  2.2420E-10  5.0725E-10  6.2269E-11
1.5000E+01  0.0000E+00  1.5156E-08  8.1733E-04  1.0568E-06  3.8716E-10  3.8224E-09  3.7332E-09  2.3931E-08  5.7273E-07  6.7764E-08
2.0000E+01  3.3723E-03  2.4748E-07  6.5910E-03  1.1099E-04  3.7408E-07  3.7445E-06  3.6558E-06  9.1202E-07
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    THE TIME IS  4.0400E+03 HOURS, WHICH IS        0 YEAR(S),  5 MONTH(S), AND  20 DAY(S) FROM THE BEGINNING.

DELT  IS 5.0000E+00 AND  DETI  IS 1.0000E+02

NORMAL RAIN

   SOIL        CUM RAIN     WATER IN    CUM EVAPO-    CUM WATER     BALANCE
   FLUX        AND FLOOD     COLUMN       TRANS       OFF BOTTOM   % OF CUMS
6.7999E-04   1.9588E+00   2.2356E+00  -3.3696E-03   1.9588E+00  -1.8427E-03

    DP           WTSOLD       VOLWAT        WNCLD         RAW          RAS            W            H            H            U
   (FT)            G*           ML           CI            CI           CI
0.0000E+00   1.2035E+04   3.5343E+02   3.5138E-08   3.5067E-08   5.0739E-07   4.9925E-02   6.8266E-03  -4.1194E+03   3.4000E-03
5.0000E-01   2.4069E+04   7.0687E+02   5.7561E-08   1.2497E-08   4.5066E-08   4.9920E-02   6.3047E-03  -4.1192E+03  -2.9562E-02
1.0000E+00   1.0831E+05   3.1810E+03   4.7500E-08   4.9512E-09   4.2557E-08   4.9926E-02   6.3049E-03  -4.1187E+03  -2.8126E-02
5.0000E+00   2.1663E+05   6.3627E+03   3.3742E-07   5.4399E-09   3.3198E-07   4.9932E-02   6.3050E-03  -4.1152E+03  -2.8125E-02
1.0000E+01   2.4069E+05   7.0797E+03   6.9712E-06   2.9044E-08   6.9021E-06   4.9940E-02   6.3050E-03  -4.1107E+03  -2.8125E-02
1.5000E+01   2.4069E+05   7.0717E+03   2.7778E-04   4.0870E-07   2.7737E-04   4.9947E-02   6.3050E-03  -4.1062E+03  -2.8124E-02
2.0000E+01   3.6104E+05   1.0609E+04   1.0541E-02   6.6774E-06   1.0533E-02   4.9954E-02   6.3050E-03  -4.1018E+03  -2.8124E-02
3.0000E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9960E-02   6.3050E-03  -4.0928E+03  -2.8124E-02
4.0000E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9964E-02   4.5600E-02  -4.0839E+03  -2.2728E-01
5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   4.5600E-02  -4.0740E+03   3.3974E-03

NUCLIDE          HALF         DECAY       ORIGINAL     REMAINING      ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
 NAME            LIFE         FACTOR       AMOUNT      ON SURFACE   COL-AN DEC     COLUMN        BOTTOM
H3            1.0821E+05   9.7824E-01   3.6000E-04   0.0000E+00   3.6000E-04   3.5072E-04   0.0000E+00   2.0000E+04   0.0000E+00
C14           5.0171E+07   9.9994E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1394E-05   0.0000E+00   2.2000E+04   1.0000E+02
S35           2.1079E+03   2.6184E-01   2.5800E-06   0.0000E+00   2.5800E-06   6.7555E-07   0.0000E+00   9.1000E+02   1.0000E+02
CR51          6.6492E+02   1.4293E-02   1.2900E-03   0.0000E+00   1.2900E-03   1.8437E-05   0.0000E+00   5.3000E+09   1.0000E+01
MN54          7.7137E+03   6.9348E-01   7.5000E-04   0.0000E+00   7.5000E-04   5.2009E-04   0.0000E+00   6.6000E+07   1.0000E+01
FE55          2.3621E+04   8.8730E-01   1.2900E-03   0.0000E+00   1.2900E-03   1.1446E-03   0.0000E+00   3.5000E+03   1.5000E+02
CO58          1.7191E+03   1.9171E-01   1.2900E-03   0.0000E+00   1.2900E-03   2.4731E-04   0.0000E+00   4.8000E+04   1.0000E+02
CO60          4.5990E+04   9.4043E-01   3.9000E-03   0.0000E+00   3.9000E-03   3.6677E-03   0.0000E+00   1.7000E+03   1.0000E+02
NI59          7.0100E+08   1.0000E+00   3.9000E-05   0.0000E+00   3.9000E-05   3.9000E-05   0.0000E+00   1.1000E-01   1.0000E+02
NI63          8.0420E+05   9.9650E-01   7.2000E-03   0.0000E+00   7.2000E-03   7.1748E-03   0.0000E+00   8.2000E+01   1.0000E+02
ZN65          5.8372E+03   6.1638E-01   6.0000E-05   0.0000E+00   6.0000E-05   3.6983E-05   0.0000E+00   7.0000E+07   1.0000E+02
SR90          2.4942E+05   9.8876E-01   1.4400E-05   0.0000E+00   1.4400E-05   1.4238E-05   0.0000E+00   2.1000E+02   2.0000E+00
NB91          3.0353E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+03   1.0000E+02
ZR95          1.5727E+03   1.6596E-01   6.0000E-05   0.0000E+00   6.0000E-05   9.9578E-06   0.0000E+00   1.8000E+08   1.0000E+02
TC99          1.8656E+09   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.4000E+02   1.0000E-01
RU106         8.8690E+03   7.2674E-01   6.0000E-05   0.0000E+00   6.0000E-05   4.3605E-05   0.0000E+00   1.9000E+08   3.0000E+02
SB124         1.4450E+03   1.4168E-01   1.5000E-05   0.0000E+00   1.5000E-05   2.1252E-06   0.0000E+00   5.1000E+04   3.0000E+00
SB125         2.4283E+04   8.9019E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.3353E-05   0.0000E+00   3.0000E+03   3.0000E+09
I125          1.4385E+03   1.4037E-01   4.5000E-06   0.0000E+00   4.5000E-06   6.3166E-07   0.0000E+00   7.6000E+06   1.0000E-01
I129          1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9200E-08   0.0000E+00   7.2000E-02   1.0000E-01
CS134         1.7461E+04   8.5448E-01   1.4400E-03   0.0000E+00   1.4400E-03   1.2304E-03   0.0000E+00   1.9000E+03   2.0000E+19
CS135         2.0394E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-03   2.0000E+01
CS137         2.6280E+05   9.8931E-01   2.5800E-03   0.0000E+00   2.5800E-03   2.5524E-03   0.0000E+00   1.3000E+02   2.0000E+01
CE144         6.8133E+03   6.6638E-01   6.0000E-05   0.0000E+00   6.0000E-05   3.9634E-05   0.0000E+00   1.8000E+06   1.0000E+02
EU152         1.1702E+05   9.7623E-01   1.4400E-07   0.0000E+00   1.4400E-07   1.4058E-07   0.0000E+00   6.5000E-03   1.2000E+03
EU154         7.4487E+04   9.6279E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.3864E-06   0.0000E+00   1.0000E-02   1.2000E+03
EU155         4.3362E+04   9.3694E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.3492E-06   0.0000E+00   1.8000E-02   1.2000E+03
RA226         1.4051E+07   9.9980E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4493E-07   0.0000E+00   5.6000E+02   5.0000E+01
TH230         7.0100E+08   1.0000E+00   2.1300E-07   0.0000E+00   2.1300E-07   2.1300E-07   0.0000E+00   2.3000E-02   1.2000E+03
TH232         1.2364E+14   1.0000E+00   2.5200E-08   0.0000E+00   2.5200E-08   2.5200E-08   0.0000E+00   1.2000E-07   1.2000E+03
U235          6.2200E+12   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   2.4000E-06   2.0000E+00
U238          3.9420E+13   1.0000E+00   2.1300E-06   0.0000E+00   2.1300E-06   2.1300E-06   0.0000E+00   3.8000E-07   2.0000E+00
NP237         1.8737E+10   1.0000E+00   1.3800E-10   0.0000E+00   1.3800E-10   1.3800E-10   0.0000E+00   8.0000E-04   7.0000E+01
PU238         7.6812E+05   9.9626E-01   9.6000E-07   0.0000E+00   9.6000E-07   9.5641E-07   0.0000E+00   6.3000E-04   2.0000E+02
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PU239   2.1[illegible]  9.999[illegible]E-01  1.2[illegible]E-07  0.0000E+00  1.2000E-07  1.2[illegible]E-07  0.0000E+00  2.2000E-06  2.0000E+02
PU240   5.7[illegible]E+07  9.9995E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0099E-07  0.0000E+00  8.5000E-06  2.0000E+02
PU241   1.15[illegible]E+05  9.75[illegible]7E-01  4.9500E-05  0.0000E+00  4.9500E-05  4.9[illegible]E-05  0.0000E+00  4.1000E-05  2.0000E+02
PU242   4.7[illegible]01E+0[illegible]  1.0000E+00  7.2000E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.4000E-07  2.0000E+02
AM241   3.7942E+06  9.9620E-01  4.0000E-08  0.0000E+00  4.0000E-08  3.9934E-08  0.0000E+00  4.1000E-05  7.0000E+01
AM242   1.6018E+01  0.0000E+00  4.0000E-09  0.0000E+00  4.0000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
AM243   6.4040E+07  9.9996E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2947E-09  0.0000E+00  7.1000E-02  7.0000E+01
CM242   3.9160E+03  4.8618E-01  7.5000E-06  0.0000E+00  7.5000E-06  3.6063E-06  0.0000E+00  4.0000E-02  7.0000E+01
CM243   2.6280E+05  9.8031E-01  1.8000E-09  0.0000E+00  1.8000E-09  1.7800E-09  0.0000E+00  6.2000E-04  7.0000E+01
CM244   1.5600E+05  9.8211E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.5980E-07  0.0000E+00  9.7000E-04  7.0000E+01

     DD          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  2.8311E-02  0.0000E+00  0.0000E+00  3.3261E-12  4.3813E-11  0.0000E+00  0.0000E+00  1.6205E-16  0.0000E+00  8.1230E-16
 5.0000E-01  0.0000E+00  2.3082E-16  0.0000E+00  7.2956E-11  2.0578E-09  6.0565E-15  1.0966E-14  1.4021E-13  1.0767E-15  2.7206E-13
 1.0000E+00  0.0000E+00  4.6076E-14  2.0478E-15  7.0327E-10  1.9836E-08  8.4774E-13  1.0832E-12  1.3804E-11  1.2957E-13  2.6006E-11
 5.0000E+00  0.0000E+00  8.8323E-12  5.2342E-13  1.2964E-08  3.6567E-07  2.5194E-10  1.4162E-10  2.6058E-09  2.5205E-11  5.0809E-09
 1.0000E+01  0.0000E+00  2.2579E-09  1.3381E-10  3.3201E-07  9.3758E-06  4.7796E-08  4.8965E-08  6.6515E-07  6.6348E-09  1.3374E-06
 1.5000E+01  0.0000E+00  4.3098E-07  2.6069E-08  6.4965E-06  1.8320E-04  2.9904E-05  9.5434E-06  1.3741E-04  1.4149E-06  2.6852E-04
 2.0000E+01  0.0000E+00  3.0377E-05  1.8002E-06  4.5069E-05  1.2706E-03  3.0604E-03  6.5905E-04  9.7766E-03  1.0399E-04  1.9125E-02

     DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  0.0000E+00  2.3227E-08  0.0000E+00  0.0000E+00  6.8091E-06  0.0000E+00  4.1274E-10  0.0000E+00  4.4802E-05  1.3433E-06
 5.0000E-01  1.5334E-15  9.8637E-08  0.0000E+00  4.1288E-16  2.0839E-07  0.0000E+00  2.6313E-09  0.0000E+00  1.0712E-06  5.9480E-08
 1.0000E+00  1.5800E-13  1.9940E-07  0.0000E+00  4.2003E-14  2.3243E-08  2.2703E-15  7.7197E-09  0.0000E+00  1.5243E-07  5.3089E-09
 5.0000E+00  2.8654E-11  7.6500E-07  0.0000E+00  7.7154E-12  6.0219E-09  1.2603E-12  4.3090E-08  0.0000E+00  3.9623E-08  1.4330E-09
 1.0000E+01  7.3251E-09  4.0747E-06  0.0000E+00  1.9723E-09  2.0615E-09  9.6635E-10  3.3401E-07  0.0000E+00  1.3564E-08  5.0495E-10
 1.5000E+01  1.4271E-06  1.6509E-05  0.0000E+00  3.8026E-07  5.4401E-10  5.0067E-07  1.9743E-06  1.7350E-14  3.6058E-09  1.3012E-10
 2.0000E+01  4.8553E-05  2.4022E-05  0.0000E+00  2.0534E-05  5.0654E-11  1.1695E-04  4.1510E-06  3.5924E-05  3.7277E-10  1.4660E-11

     DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  0.0000E+00  0.0000E+00  6.4907E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 5.0000E-01  0.0000E+00  9.2678E-15  2.8973E-10  1.6435E-15  0.0000E+00  0.0000E+00  0.0000E+00  2.2411E-16  0.0000E+00  0.0000E+00
 1.0000E+00  0.0000E+00  1.9073E-13  5.7234E-09  1.0720E-13  0.0000E+00  0.0000E+00  0.0000E+00  2.3011E-14  0.0000E+00  0.0000E+00
 5.0000E+00  0.0000E+00  7.4356E-12  2.1666E-07  3.0711E-11  9.5715E-18  5.0735E-16  4.9407E-16  2.1151E-12  4.2783E-17  0.0000E+00
 1.0000E+01  0.0000E+00  4.0398E-10  1.1921E-05  7.8510E-09  1.7260E-13  1.7713E-12  1.0565E-12  2.7044E-10  2.0342E-11  2.5702E-14
 1.5000E+01  0.0000E+00  1.6757E-08  4.5926E-08  1.5246E-06  4.2873E-10  4.2267E-09  4.1142E-09  2.6353E-09  6.5164E-10  6.9917E-11
 2.0000E+01  3.3108E-03  2.4686E-07  6.5537E-03  1.0563E-04  3.7797E-07  3.7274E-06  3.6275E-06  9.1035E-07  5.7268E-07  6.7759E-08
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      THE TIME IS  4.3200E+03 HOURS, WHICH IS         0 YEAR(S),  6 MONTH(S), AND   0 DAY(S) FROM THE BEGINNING.

 DELT  IS 2.5000E+00 AND  DETT  IS 5.0000E+01

 DRY PERIOD

     SOIL        CUM RAIN      WATER IN    CUM EVAPO-    CUM WATER    BALANCE
     FLUX        AND FLOOD      COLUMN       TRANS      OFF BOTTOM   % OF CUMS
 -2.0000E-06   1.9584E+00   2.2355E+00 -3.4996E-03   1.9586E+00 -2.0037E-03

      DD          WTSOLD        VOLWAT        RNCLD          RAW           RAS           W             D             M             U
     (FT)           GM            ML            CI            CI            CI
  0.0000E+00   1.2035E+04   3.5333E+02   3.5070E-04   3.5031E-08   4.2940E-07   4.9910E-02   6.3049E-03 -4.1240E+03 -5.0000E-06
  5.0000E-01   2.4069E+04   7.0677E+02   1.6565E-07   2.3147E-08   8.2504E-08   4.9919E-02   6.3057E-03 -4.1235E+03 -1.5792E-02
  1.0000E+00   1.0831E+05   3.1805E+03   4.8137E-08   3.1468E-09   4.5290E-08   4.9919E-02   6.3049E-03 -4.1230E+03 -1.5769E-02
  5.0000E+00   2.1663E+05   6.3619E+03   4.1297E-07   5.0693E-09   4.0791E-07   4.9926E-02   6.3051E-03 -4.1190E+03 -1.5766E-02
  1.0000E+01   2.4069E+05   7.0699E+03   8.0951E-06   3.2700E-08   8.0624E-06   4.9934E-02   6.3050E-03 -4.1140E+03 -1.5767E-02
  1.5000E+01   2.4069E+05   7.0711E+03   2.9931E-04   4.3482E-07   2.9894E-04   4.9942E-02   6.3059E-03 -4.1090E+03 -1.5766E-02
  2.0000E+01   3.6104E+05   1.0608E+04   1.6439E-02   8.5819E-06   1.6431E-02   4.9951E-02   6.3050E-03 -4.1040E+03 -1.5766E-02
  3.0000E+01   4.8139E+05   1.4149E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9967E-02   6.3050E-03 -4.0900E+03 -1.5766E-02
  4.0000E+01   4.8139E+05   1.4158E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9981E-02   9.5599E-02 -4.0840E+03 -1.2741E-01
  5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   9.5599E-02 -4.0740E+03 -3.6468E-06

 NUCLIDE          HALF         DECAY        ORIGINAL      REMAINING      ENTERED      AMOUNT IN    AMOUNT OFF    SOLUBILITY   KD BASALT
  NAME            LIFE         FACTOR        AMOUNT       ON SURFACE   COL-NO DEC      COLUMN        BOTTOM
 H3            1.0821E+05   9.7272E-01   3.6000E-04   0.0000E+00   3.6000E-04   3.5014E-04   0.0000E+00   2.6000E+04   0.0000E+00
 C14           5.0171E+07   9.9998E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1399E-05   0.0000E+00   2.2000E+09   1.0000E+02
 S35           2.1079E+03   2.4177E-01   2.5800E-06   0.0000E+00   2.5800E-06   6.2374E-07   0.0000E+00   9.1000E+02   1.0000E+02
 CR51          6.6492E+02   1.1100E-02   1.2900E-03   0.0000E+00   1.2900E-03   1.4319E-05   0.0009E+00   5.3000E+09   1.0000E+01
 MN54          7.7137E+03   6.7843E-01   7.5000E-04   0.0000E+00   7.5000E-04   5.0883E-04   0.0000E+00   6.6000E+07   1.0000E+01
 FE55          2.3621E+04   8.8100E-01   1.2900E-03   0.0000E+00   1.2900E-03   1.1365E-03   0.0000E+00   3.5000E+03   1.5000E+02
 CO58          1.7101E+03   1.7377E-01   1.2900E-03   0.0000E+00   1.2900E-03   2.2416E-04   0.0000E+00   4.8000E+04   1.0000E+02
 CO60          4.5990E+04   9.3700E-01   3.9000E-03   0.0000E+00   3.9000E-03   3.6543E-03   0.0000E+00   1.7000E+03   1.0000E+02
 NI59          7.0100E+08   1.0000E+00   3.9000E-05   0.0000E+00   3.9000E-05   3.9001E-05   0.0000E+00   1.1000E-01   1.0000E+02
 NI63          6.0620E+05   9.9629E-01   7.2000E-03   0.0000E+00   7.2000E-03   7.1735E-03   0.0000E+00   8.2000E+01   1.0000E+02
 ZN65          5.8372E+03   5.9888E-01   6.0000E-05   0.0000E+00   6.0000E-05   3.5933E-05   0.0000E+00   7.0000E+07   1.0000E+02
 SR90          2.4962E+05   9.8809E-01   1.4400E-05   0.0000E+00   1.4400E-05   1.4229E-05   0.0000E+00   2.1000E+02   2.0000E+00
 NB94          3.0343E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+03   1.0000E+02
 ZR95          1.5727E+03   1.4918E-01   6.0000E-05   0.0000E+00   6.0000E-05   8.9485E-06   0.0000E+00   1.8000E+08   1.0000E+02
 TC99          1.8565E+09   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.4000E+02   1.0000E-01
 RU106         8.8894E+03   7.1307E-01   6.0000E-05   0.0000E+00   6.0000E-05   4.2784E-05   0.0000E+00   1.9000E+08   3.0000E+02
 SB124         1.4450E+03   1.2613E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.8919E-06   0.0000E+00   5.1000E+04   3.0000E+00
 SB125         2.4283E+04   8.8405E-01   1.5000E-05   0.0000E+00   1.5000E-05   1.3261E-05   0.0000E+00   3.0000E+03   3.0000E+09
 I125          1.4385E+03   1.2489E-01   4.5000E-06   0.0000E+00   4.5000E-06   5.6200E-07   0.0000E+00   7.6000E+06   1.0000E-01
 I129          1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9200E-08   0.0000E+00   7.2000E-02   1.0000E-01
 CS134         1.7961E+04   8.4652E-01   1.4400E-03   0.0000E+00   1.4400E-03   1.2190E-03   0.0000E+00   1.9000E+03   2.0000E+19
 CS135         2.6394E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-03   2.0000E+01
 CS137         2.6280E+05   9.8888E-01   2.5800E-03   0.0000E+00   2.5800E-03   2.5500E-03   0.0000E+00   1.3000E+02   2.0000E+01
 CE144         6.8133E+03   6.4453E-01   6.0000E-05   0.0000E+00   6.0000E-05   3.8672E-05   0.0000E+00   1.8000E+08   1.0000E+02
 EU152         1.1742E+05   9.7488E-01   1.4400E-07   0.0000E+00   1.4400E-07   1.4038E-07   0.0000E+00   6.5000E-03   1.2000E+03
 EU154         7.4867E+04   9.6082E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.3835E-06   0.0000E+00   1.0000E-02   1.2000E+03
 EU155         4.3362E+04   9.3331E-01   1.4400E-06   0.0000E+00   1.4400E-06   1.3440E-06   0.0000E+00   1.8000E-02   1.2000E+03
 RA226         1.4053E+07   9.9979E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4493E-07   0.0000E+00   5.6000E+02   5.0000E+01
 TH230         7.0100E+08   1.0000E+00   2.1300E-07   0.0000E+00   2.1300E-07   2.1300E-07   0.0000E+00   2.3000E-02   1.2000E+03
 TH232         1.2360E+14   1.0000E+00   2.5200E-08   0.0000E+00   2.5200E-08   2.5200E-08   0.0000E+00   1.2000E-07   1.2000E+03
 U235          6.2200E+12   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   2.4000E-06   2.0000E+00
 U238          3.9420E+13   1.0000E+00   2.1300E-06   0.0000E+00   2.1300E-06   2.1300E-06   0.0000E+00   3.8000E-07   2.0000E+00
 NP237         1.9757E+10   1.0000E+00   1.3800E-10   0.0000E+00   1.3800E-10   1.3800E-10   0.0000E+00   8.0000E-04   7.0000E+01
 PU238         7.5412E+05   9.9604E-01   9.6000E-07   0.0000E+00   9.6000E-07   9.5620E-07   0.0000E+00   6.3000E-04   2.0000E+02
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   PU239     2.1100E+08  9.9999E-01  1.2900E-07  0.0000E+00  1.2900E-07  1.2900E-07  0.0000E+00  2.2000E-06  2.0000E+02
   PU240     5.7310E+07  9.9995E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0099E-07  0.0000E+00  6.3000E-05  2.0000E+02
   PU241     1.1563E+05  9.7445E-01  4.9500E-05  0.0000E+00  4.9500E-05  4.8235E-05  0.0000E+00  4.1000E-03  2.0000E+02
   PU242     4.7811E+09  1.0000E+00  7.2000E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.0000E-07  2.0000E+02
   AM241     3.7942E+06  9.9921E-01  9.0000E-08  0.0000E+00  9.0000E-08  8.9927E-08  0.0000E+00  4.1000E-05  7.0000E+01
   AM242     1.6018E+01  0.0000E+00  4.4000E-09  0.0000E+00  4.4000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
   AM243     6.4648E+07  9.9996E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2997E-09  0.0000E+00  7.1000E-02  7.0000E+01
   CM242     3.9166E+03  4.6575E-01  7.5000E-06  0.0000E+00  7.5000E-06  3.4931E-06  0.0000E+00  4.0000E-02  7.0000E+01
   CM243     2.6240E+05  9.6808E-01  1.4900E-09  0.0000E+00  1.4900E-09  1.7746E-09  0.0000E+00  6.2000E-04  7.0000E+01
   CM244     1.5866E+05  9.8105E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.5924E-07  0.0000E+00  4.7000E-04  7.0000E+01

      DD          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
   0.0000E+00  2.8206E-02  0.0000E+00  0.0000E+00  3.8076E-12  1.3530E-10  0.0000E+00  0.0000E+00  4.6959E-16  0.0000E+00  1.4141E-15
   5.0000E-01  0.0000E+00  4.8421E-16  0.0000E+00  8.4313E-11  2.9961E-09  9.1135E-15  1.4758E-14  2.1158E-13  1.7603E-15  4.1333E-13
   1.0000E+00  0.0000E+00  6.6894E-14  3.6593E-15  7.5489E-10  2.6789E-08  1.2471E-12  1.3156E-12  1.9313E-11  1.8988E-13  3.7760E-11
   5.0000E+00  0.0000E+00  1.1352E-11  6.2117E-13  1.2837E-08  4.5614E-07  3.2174E-10  2.2322E-10  3.3606E-09  3.2887E-11  6.5773E-09
   1.0000E+01  0.0000E+00  2.6734E-09  1.4639E-10  3.0326E-07  1.0774E-05  1.1534E-07  5.2575E-08  8.1229E-07  8.1772E-09  1.5914E-06
   1.5000E+01  0.0000E+00  4.7805E-07  2.6159E-08  5.4348E-06  1.9339E-04  3.1391E-05  9.4005E-06  1.4915E-04  1.5457E-06  2.9250E-04
   2.0000E+01  0.0000E+00  3.0352E-05  1.6609E-06  3.4601E-05  1.2328E-03  3.0471E-03  5.9644E-04  9.7327E-03  1.0390E-04  1.9105E-02

      DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
   0.0000E+00  0.0000E+00  3.3477E-08  0.0000E+00  0.0000E+00. 6.5591E-06  0.0000E+00  5.3173E-10  0.0000E+00  3.7227E-05  1.2601E-06
   5.0000E-01  2.2775E-15  1.4405E-07  0.0000E+00  5.6718E-16  5.8184E-07  0.0000E+00  3.4241E-09  0.0000E+00  3.4062E-06  1.1799E-07
   1.0000E+00  2.1089E-13  2.6766E-07  0.0000E+00  5.2518E-14  1.4871E-08  3.1088E-15  4.2918E-09  0.0000E+00  8.7072E-08  3.4819E-09
   5.0000E+00  3.5763E-11  9.4677E-07  0.0000E+00  8.9111E-12  3.5542E-09  1.5903E-12  4.7908E-08  0.0000E+00  2.0607E-08  8.5253E-10
   1.0000E+01  8.4278E-09  4.6375E-06  0.0000E+00  2.0988E-09  1.1235E-09  1.1231E-09  3.4217E-07  0.0000E+00  6.5774E-09  2.7660E-10
   1.5000E+01  1.5069E-05  1.7274E-05  0.0000E+00  3.7527E-07  2.7559E-10  6.0248E-07  1.0565E-06  1.8702E-14  1.6133E-09  6.9634E-11
   2.0000E+01  4.5675E-05  2.3018E-05  0.0000E+00  2.3826E-05  2.7114E-11  1.1472E-08  3.5924E-06  3.5881E-05  1.5873E-10  7.0165E-12

      DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
   0.0000E+00  0.0000E+00  0.0000E+00  9.5748E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
   5.0000E-01  0.0000E+00  1.4236E-14  4.3742E-10  2.4511E-15  0.0000E+00  0.0000E+00  0.0000E+00  4.6346E-16  0.0000E+00  0.0000E+00
   1.0000E+00  0.0000E+00  2.6970E-13  8.0062E-09  2.2696E-13  0.0000E+00  0.0000E+00  0.0000E+00  3.1991E-14  0.0000E+00  0.0000E+00
   5.0000E+00  0.0000E+00  4.6886E-12  2.7935E-07  3.8518E-11  2.5771E-17  6.0586E-16  6.4735E-16  2.7160E-12  6.7549E-17  0.0000E+00
   1.0000E+01  0.0000E+00  4.8165E-10  1.3536E-05  9.0701E-09  2.0642E-13  2.0327E-12  1.9754E-12  3.1995E-10  3.1522E-13  3.1293E-14
   1.5000E+01  0.0000E+00  1.8241E-08  4.9929E-04  1.6218E-06  4.0905E-10  4.6107E-09  4.4807E-09  2.8618E-08  7.1249E-10  7.7088E-11
   2.0000E+01  3.2749E-03  2.4542E-07  6.5220E-03  1.0297E-04  3.7740E-07  3.7191E-06  3.6132E-06  9.0880E-07  5.7264E-07  6.7754E-08
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     THE TIME IS  8.6400E+03 HOURS, WHICH IS         0 YEAR(S), 12 MONTH(S), AND    0 DAY(S) FROM THE BEGINNING.

 DELT  IS 2.5000E+00 AND  DETT  IS 5.0000E+01

 DRY PERIOD

    SOIL       CUM RAIN      WATER IN    CUM EVAPO-    CUM WATER     BALANCE
    FLUX       AND FLOOD      COLUMN       TRANS      OFF BOTTOM    % OF CUMS
 -2.0000E-05  3.9168E+00  2.2355E+00 -6.7290E-03  3.9158E+00 -3.0054E-03

     DD          WTSOLD        VOLWAT        WNCLD          WAW           WAS             W             B             H             U
    (FT)          GM            ML            CI             CI            CI
 0.0000E+00  1.2035E+04  3.5333E+02  3.4080E-04  3.4066E-04  1.3930E-07  4.9910E-02  6.3051E-03 -4.1240E+03 -5.0000E-06
 5.0000E-01  2.4069E+04  7.0677E+02  9.3721E-08  6.6631E-09  8.7058E-08  4.9914E-02  6.3047E-03 -4.1235E+03 -1.5781E-02
 1.0000E+00  1.0031E+05  3.1805E+03  3.3619E-07  4.3767E-09  3.3180E-07  4.9919E-02  6.3049E-03 -4.1230E+03 -1.5766E-02
 5.0000E+00  2.1663E+05  6.3619E+03  2.0592E-06  1.7929E-08  2.0413E-06  4.9926E-02  6.3050E-03 -4.1190E+03 -1.5767E-02
 1.0000E+01  2.4069E+05  7.0649E+03  2.4739E-05  8.2803E-08  2.4607E-05  4.9934E-02  6.3050E-03 -4.1140E+03 -1.5767E-02
 1.5000E+01  2.4069E+05  7.0711E+03  5.3976E-04  6.6721E-07  5.3019E-04  4.9942E-02  6.3050E-03 -4.1090E+03 -1.5766E-02
 2.0000E+01  3.6104E+05  1.0608E+04  1.5163E-02  7.5294E-06  1.5155E-02  4.9951E-02  6.3050E-03 -4.1040E+03 -1.5766E-02
 3.0000E+01  4.8139E+05  1.4149E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9967E-02  6.3050E-03 -4.0940E+03 -1.5766E-02
 4.0000E+01  4.8139E+05  1.4150E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9983E-02  9.5549E-02 -4.0840E+03 -1.2741E-01
 5.0000E+01  2.4069E+05  1.4159E+04  0.0000E+00  0.0000E+00  0.0000E+00  1.0000E-01  9.5549E-02 -4.0740E+03 -2.4174E-06

 NUCLIDE         HALF        DECAY       ORIGINAL     REMAINING     ENTERED     AMOUNT IN   AMOUNT OFF   SOLUBILITY   KD BASALT
  NAME           LIFE        FACTOR       AMOUNT     ON SURFACE   COL-AD DEC     COLUMN      BOTTOM
 H3          1.0821E+05  9.4618E-01  3.6000E-04  0.0000E+00  3.6000E-04  3.4062E-04  0.0000E+00  2.6000E+04  0.0000E+00
 C14         5.0171E+07  9.9988E-01  1.1400E-05  0.0000E+00  1.1400E-05  1.1349E-05  0.0000E+00  2.2000E+09  1.0000E+02
 S35         2.1079E+03  5.8006E-02  2.5900E-06  0.0000E+00  2.5900E-06  1.5069E-07  0.0000E+00  9.1000E+02  1.0000E+02
 CR51        6.6492E+02  1.2289E-04  1.2900E-03  0.0000E+00  1.2900E-03  1.5853E-07  0.0000E+00  5.3000E+09  1.0000E+01
 MN54        7.7137E+03  4.6017E-01  7.5000E-04  0.0000E+00  7.5000E-04  3.4513E-04  0.0000E+00  6.6000E+07  1.0000E+01
 FE55        2.3621E+04  7.7611E-01  1.2900E-03  0.0000E+00  1.2900E-03  1.0012E-03  0.0000E+00  3.5000E+03  1.5000E+02
 CO58        1.7101E+03  3.0164E-02  1.2900E-03  0.0000E+00  1.2900E-03  3.8912E-05  0.0000E+00  4.0000E+04  1.0000E+02
 CO60        4.5990E+04  8.7794E-01  3.9000E-03  0.0000E+00  3.9000E-03  3.4239E-03  0.0000E+00  1.7000E+03  1.0000E+02
 NI59        7.0100E+08  9.9999E-01  3.9000E-05  0.0000E+00  3.9000E-05  3.9000E-05  0.0000E+00  1.1000E-01  1.0000E+02
 NI63        8.0620E+05  9.9260E-01  7.2000E-03  0.0000E+00  7.2000E-03  7.1467E-03  0.0000E+00  8.2000E+01  1.0000E+02
 ZN65        5.8372E+03  3.5855E-01  6.0000E-05  0.0000E+00  6.0000E-05  2.1513E-05  0.0000E+00  7.0000E+07  1.0000E+02
 SR90        2.4982E+05  9.7632E-01  1.4400E-05  0.0000E+00  1.4400E-05  1.4059E-05  0.0000E+00  2.1000E+02  2.0000E+00
 NB94        3.0353E-01  0.0000E+00  4.2000E-07  0.0000E+00  4.2000E-07  0.0000E+00  0.0000E+00  1.6000E+03  1.0000E+02
 ZR95        1.5727E+03  2.2218E-02  6.0000E-05  0.0000E+00  6.0000E-05  1.3331E-06  0.0000E+00  1.8000E+08  1.0000E+02
 TC99        1.8565E+09  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  1.4000E+02  1.0000E-01
 RU106       8.8498E+03  5.0837E-01  6.0000E-05  0.0000E+00  6.0000E-05  3.0502E-05  0.0000E+00  1.9000E+08  3.0000E+02
 SB124       1.4454E+03  1.5889E-02  1.5000E-05  0.0000E+00  1.5000E-05  2.3833E-07  0.0000E+00  5.1000E+04  3.0000E+00
 SB125       2.4283E+04  7.8149E-01  1.5000E-05  0.0000E+00  1.5000E-05  1.1722E-05  0.0000E+00  3.0000E+03  3.0000E+09
 I125        1.4365E+03  1.5578E-02  4.5000E-06  0.0000E+00  4.5000E-06  7.0103E-08  0.0000E+00  7.6000E+06  1.0000E-01
 I129        1.4916E+11  1.0000E+00  1.9200E-08  0.0000E+00  1.9200E-08  1.9200E-08  0.0000E+00  7.2000E-02  1.0000E-01
 CS134       1.7461E+04  7.1652E-01  1.4400E-03  0.0000E+00  1.4400E-03  1.0318E-03  0.0000E+00  1.9000E+03  2.0000E+19
 CS135       2.6394E+10  1.0000E+00  9.0000E-08  0.0000E+00  9.0000E-08  9.0000E-08  0.0000E+00  1.7000E-03  2.0000E+01
 CS137       2.6280E+05  9.7748E-01  2.5800E-03  0.0000E+00  2.5800E-03  2.5219E-03  0.0000E+00  1.3000E+02  2.0000E+01
 CE144       6.8133E+03  4.1531E-01  6.0000E-05  0.0000E+00  6.0000E-05  2.4919E-05  0.0000E+00  1.0000E+00  1.0000E+02
 EU152       1.1742E+05  9.5029E-01  1.4400E-07  0.0000E+00  1.4400E-07  1.3684E-07  0.0000E+00  6.5000E-03  1.2000E+03
 EU154       7.4487E+04  9.2277E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.3288E-06  0.0000E+00  1.0000E-02  1.2000E+03
 EU155       4.3362E+04  8.7108E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.2543E-06  0.0000E+00  1.0000E-02  1.2000E+03
 RA226       1.4053E+07  9.9957E-01  3.4500E-07  0.0000E+00  3.4500E-07  3.4485E-07  0.0000E+00  5.6000E+02  5.0000E+01
 TH230       7.6100E+08  9.9999E-01  2.1300E-07  0.0000E+00  2.1300E-07  2.1300E-07  0.0000E+00  2.3000E-02  1.2000E+03
 TH232       1.2364E+14  1.0000E+00  2.5200E-08  0.0000E+00  2.5200E-08  2.5200E-08  0.0000E+00  1.2000E-07  1.2000E+03
 U234        6.2200E+12  1.0000E+00  4.8000E-08  0.0000E+00  4.8000E-08  4.8000E-08  0.0000E+00  2.4000E-06  2.0000E+00
 U238        3.9420E+13  1.0000E+00  2.1300E-06  0.0000E+00  2.1300E-06  2.1300E-06  0.0000E+00  3.8000E-07  2.0000E+00
 NP237       1.8757E+10  1.0000E+00  1.3800E-10  0.0000E+00  1.3800E-10  1.3800E-10  0.0000E+00  8.0000E-04  7.0000E+01
 PU238       7.5012E+05  9.9209E-01  9.6000E-07  0.0000E+00  9.6000E-07  9.5241E-07  0.0000E+00  6.3000E-04  2.0000E+02
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     PU239      2.1[illegible]E+04  9.9937E-01  1.2900E-07  0.0000E+00  1.2900E-07  1.2900E-07  0.0000E+00  2.2000E-06  2.0000E+02
     PU240      5.7016E+07  9.9990E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0998E-07  0.0000E+00  5.3000E-06  2.0000E+02
     PU241      1.1563E+05  9.4954E-01  4.9500E-05  0.0000E+00  4.9500E-05  4.7002E-05  0.0000E+00  4.1000E-03  2.0000E+02
     PU242      4.7601E+07  1.0000E+00  7.2000E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.4000E-07  2.0000E+02
     AM241      3.7942E+06  9.9842E-01  9.0000E-08  0.0000E+00  9.0000E-08  8.9854E-08  0.0000E+00  4.1000E-05  7.0000E+01
     AM242      1.0018E+01  0.0000E+00  4.4000E-09  0.0000E+00  4.4000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
     AM243      6.9698E+07  9.9991E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2995E-09  0.0000E+00  7.1000E-02  7.0000E+01
     CM242      3.4166E+03  2.1683E-01  7.5000E-06  0.0000E+00  7.5000E-06  1.6262E-06  0.0000E+00  4.0000E-02  7.0000E+01
     CM243      2.0283E+05  9.7748E-01  1.8000E-09  0.0000E+00  1.8000E-09  1.7595E-09  0.0000E+00  6.2000E-04  7.0000E+01
     CM244      1.5644E+05  9.6246E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.4860E-07  0.0000E+00  9.7000E-04  7.0000E+01


      DD          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM''
  0.0000E+00  2.7496E-02  0.0000E+00  0.0000E+00  2.0178E-12  4.3930E-09  5.1694E-16  5.7844E-16  4.8214E-14  0.0000E+00  1.0084E-13
  5.0000E-01  0.0000E+00  2.0673E-14  2.5455E-16  2.3557E-11  5.1287E-08  2.3494E-13  7.1445E-14  5.0863E-12  6.2274E-14  1.2256E-11
  1.0000E+00  0.0000E+00  9.0006E-13  1.2956E-14  1.1087E-10  2.4139E-07  1.0624E-11  3.3457E-12  2.7920E-10  3.0045E-12  5.0164E-10
  5.0000E+00  0.0000E+00  8.6360E-11  1.1417E-12  9.8132E-10  2.1364E-06  2.2132E-09  2.9481E-10  2.0926E-08  2.7201E-10  5.1951E-08
  1.0000E+01  0.0000E+00  1.0436E-08  1.3796E-10  1.1898E-08  2.5904E-05  4.0418E-07  3.5626E-08  3.0527E-06  3.3785E-08  6.3646E-06
  1.5000E+01  0.0000E+00  9.4587E-07  1.2504E-08  1.0825E-07  2.3567E-04  5.5460E-05  3.2289E-06  2.8037E-04  3.1403E-06  5.8492E-04
  2.0000E+01  0.0000E+00  3.0033E-05  3.9703E-07  3.4582E-07  7.5290E-04  2.6567E-03  1.0252E-04  9.0234E-03  1.0281E-04  1.8836E-02


      DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
  0.0000E+00  0.0000E+00  1.1599E-06  0.0000E+00  0.0000E+00  6.7010E-06  0.0000E+00  2.5692E-09  0.0000E+00  4.8933E-06  1.3402E-06
  5.0000E-01  3.9448E-14  2.4653E-06  0.0000E+00  2.4445E-15  5.2410E-07  0.0000E+00  8.4594E-09  0.0000E+00  3.8272E-07  1.0483E-07
  1.0000E+00  1.6497E-12  2.3884E-06  0.0000E+00  1.1462E-13  1.6538E-11  3.2869E-14  1.2041E-08  0.0000E+00  1.2074E-11  4.0854E-12
  5.0000E+00  1.6299E-10  4.3603E-06  0.0000E+00  1.0100E-11  2.2070E-12  8.0883E-12  3.2844E-08  0.0000E+00  1.6116E-12  5.5169E-13
  1.0000E+01  1.9697E-08  1.0858E-05  0.0000E+00  1.2205E-09  3.7203E-13  3.1490E-09  1.1904E-07  0.0000E+00  2.7167E-13  9.4185E-14
  1.5000E+01  1.7852E-06  2.0326E-05  0.0000E+00  1.1062E-07  4.9255E-14  8.5548E-07  3.2807E-07  3.3135E-14  3.5968E-14  1.2622E-14
  2.0000E+01  5.6682E-05  1.3504E-05  0.0000E+00  3.5124E-06  2.8066E-15  8.1494E-05  3.1947E-07  3.1541E-05  2.0787E-15  7.3661E-16


      DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
     (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
  0.0000E+00  0.0000E+00  1.7408E-14  5.1380E-10  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
  5.0000E-01  0.0000E+00  4.3789E-13  1.2316E-08  4.5692E-14  0.0000E+00  0.0000E+00  0.0000E+00  1.9546E-14  0.0000E+00  0.0000E+00
  1.0000E+00  0.0000E+00  4.2236E-12  1.1717E-07  2.1925E-12  0.0000E+00  0.0000E+00  0.0000E+00  4.6363E-13  0.0000E+00  0.0000E+00
  5.0000E+00  0.0000E+00  7.6641E-11  2.0971E-06  1.8879E-10  5.2142E-16  5.4564E-15  5.1526E-15  2.0437E-11  8.4316E-16  0.0000E+00
  1.0000E+01  0.0000E+00  1.9070E-09  5.1461E-05  2.2814E-08  8.3960E-13  8.1501E-12  7.6950E-12  1.2353E-09  1.3110E-12  1.4258E-13
  1.5000E+01  0.0000E+00  3.5608E-08  9.4740E-04  2.0678E-06  9.3852E-10  4.1119E-09  8.6020E-09  5.6004E-08  1.4631E-09  1.6591E-10
  2.0000E+01  2.7763E-03  2.3325E-07  6.1184E-03  6.5655E-05  3.6757E-07  3.5691E-06  3.3692E-06  8.8972E-07  5.7214E-07  6.7695E-08
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     THE TIME IS  1.7280E+04 HOURS, WHICH IS        1 YEAR(S), 11 MONTH(S), AND  25 DAY(S) FROM THE BEGINNING.

  DELT  IS 2.5000E+00 AND  DLTT  IS 5.0000E+01

  DRY PERIOD

     SOIL       CUM RAIN     WATER IN    CUM EVAPO-    CUM WATER     BALANCE
     FLUX      AND FLOOD      COLUMN       TRANS      OFF BOTTOM   % OF CUMS
  -2.0000E-06  7.8336E+00  2.2355E+00 -1.2490E-02  7.8241E+00 -6.0003E-03

      DP          WTSOLD       VOLWAT      WNCLD        WAY          WAB           W            B            H            Q
     (FT)           GM           ML          CI          CI           CI
  0.0000E+00  1.2035E+04  3.5333E+02  3.2276E-08  5.2231E-04  4.4766E-07  4.9910E-02  6.3049E-03 -4.1280E+03 -5.0000E-06
  5.0000E-01  2.4009E+04  7.0677E+02  7.5140E-07  1.3946E-08  7.5749E-07  4.9914E-02  6.3057E-03 -4.1235E+03 -1.5777E-02
  1.0000E+00  1.0831E+05  3.1805E+03  1.9239E-06  2.3695E-08  1.9002E-06  4.9919E-02  6.3049E-03 -4.1230E+03 -1.5764E-02
  5.0000E+00  2.1663E+05  6.3619E+03  7.7937E-06  5.2191E-08  7.7416E-06  4.9926E-02  6.3050E-03 -4.1190E+03 -1.5767E-02
  1.0000E+01  2.4009E+05  7.0699E+03  6.7944E-05  1.5760E-07  6.7786E-05  4.9934E-02  6.3051E-03 -4.1140E+03 -1.5766E-02
  1.5000E+01  2.4009E+05  7.0711E+03  8.9160E-04  9.1820E-07  8.9072E-04  4.9942E-02  6.3050E-03 -4.1090E+03 -1.5766E-02
  2.0000E+01  3.0104E+05  1.0608E+04  1.3430E-02  6.2431E-06  1.3423E-02  4.9951E-02  6.3050E-03 -4.1040E+03 -1.5766E-02
  3.0000E+01  4.8139E+05  1.4149E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9967E-02  6.3050E-03 -4.0940E+03 -1.5766E-02
  4.0000E+01  4.8139E+05  1.4154E+04  0.0000E+00  0.0000E+00  0.0000E+00  4.9984E-02  9.5549E-02 -4.0840E+03 -1.2741E-01
  5.0000E+01  2.4009E+05  1.4159E+04  0.0000E+00  0.0000E+00  0.0000E+00  1.0000E-01  9.5549E-02 -4.0740E+03 -3.6406E-06

  NUCLIDE          HALF        DECAY       ORIGINAL    REMAINING      ENTERED     AMOUNT IN   AMOUNT OFF   SOLUBILITY   KD BASALT
   NAME            LIFE        FACTOR       AMOUNT     ON SURFACE   COL-AN DEC     COLUMN       BOTTOM
  H3            1.0821E+05  8.9523E-01  3.6000E-04  0.0000E+00  3.6000E-04  3.2228E-04  0.0000E+00  2.6000E+04  0.0000E+00
  C14           5.0171E+07  9.9976E-01  1.1400E-05  0.0000E+00  1.1400E-05  1.1397E-05  0.0000E+00  2.2000E+09  1.0000E+02
  S35           2.1079E+03  3.4045E-03  2.5800E-06  0.0000E+00  2.5800E-06  8.7900E-09  0.0000E+00  9.1000E+02  1.0000E+02
  CR51          6.0492E+02  0.0000E+00  1.2900E-03  0.0000E+00  1.2900E-03  0.0000E+00  0.0000E+00  5.3000E+05  1.0000E+01
  MN54          7.7137E+03  2.1171E-01  7.5000E-04  0.0000E+00  7.5000E-04  1.5874E-04  0.0000E+00  6.6000E+07  1.0000E+01
  FE55          2.3621E+04  6.0230E-01  1.2900E-03  0.0000E+00  1.2900E-03  7.7697E-04  0.0000E+00  3.5060E+03  1.5000E+02
  CO58          1.7101E+03  9.0894E-04  1.2900E-03  0.0000E+00  1.2900E-03  1.1726E-06  0.0000E+00  4.8000E+04  1.0000E+02
  CO60          4.5990E+04  7.7074E-01  3.9000E-03  0.0000E+00  3.9000E-03  3.0059E-03  0.0000E+00  1.7000E+03  1.0000E+02
  NI59          7.0100E+08  9.9998E-01  3.9000E-05  0.0000E+00  3.9000E-05  3.8999E-05  0.0000E+00  1.1000E-01  1.0000E+02
  NI63          8.0620E+05  9.8526E-01  7.2000E-03  0.0000E+00  7.2000E-03  7.0938E-03  0.0000E+00  8.2000E+01  1.0000E+02
  ZN65          5.8372E+03  1.2852E-01  6.0000E-05  0.0000E+00  6.0000E-05  7.7114E-06  0.0000E+00  7.0000E+07  1.0000E+02
  SR90          2.4902E+05  9.5319E-01  1.4400E-05  0.0000E+00  1.4400E-05  1.3726E-05  0.0000E+00  2.1000E+02  2.0000E+00
  NB94          3.0353E-01  0.0000E+00  4.2000E-07  0.0000E+00  4.2000E-07  0.0000E+00  0.0000E+00  1.6000E+03  1.0000E+02
  ZR95          1.5727E+03  4.9312E-04  6.0000E-05  0.0000E+00  6.0000E-05  2.9587E-08  0.0000E+00  1.8000E+08  1.0000E+02
  TC99          1.8505E+09  9.9999E-01  9.6000E-08  0.0000E+00  9.6000E-08  9.5999E-08  0.0000E+00  1.4000E+02  1.0000E-01
  RU106         8.8494E+03  2.5839E-01  6.0000E-05  0.0000E+00  6.0000E-05  1.5503E-05  0.0000E+00  1.9000E+08  3.0000E+02
  SB124         1.4454E+03  2.5215E-04  1.5000E-05  0.0000E+00  1.5000E-05  3.7822E-09  0.0000E+00  5.1000E+04  3.0000E+00
  SB125         2.4283E+04  6.1068E-01  1.5000E-05  0.0000E+00  1.5000E-05  9.1602E-06  0.0000E+00  3.0000E+03  3.0000E+09
  I125          1.4385E+03  2.4239E-04  4.5000E-06  0.0000E+00  4.5000E-06  1.0908E-09  0.0000E+00  7.6000E+06  1.0000E-01
  I129          1.4916E+11  1.0000E+00  1.9200E-08  0.0000E+00  1.9200E-08  1.9200E-08  0.0000E+00  7.2000E-02  1.0000E-01
  CS134         1.7961E+04  5.1336E-01  1.4400E-03  0.0000E+00  1.4400E-03  7.3923E-04  0.0000E+00  1.9000E+03  2.0000E+19
  CS135         2.0598E+10  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  1.7000E-03  2.0000E+01
  CS137         2.6280E+05  9.5545E-01  2.5800E-03  0.0000E+00  2.5800E-03  2.4651E-03  0.0000E+00  1.3000E+02  2.0000E+01
  CE144         6.8733E+03  1.7244E-01  6.0000E-05  0.0000E+00  6.0000E-05  1.0346E-05  0.0000E+00  1.8000E+00  1.0000E+02
  EU152         1.1742E+05  9.0304E-01  1.4400E-07  0.0000E+00  1.4400E-07  1.3004E-07  0.0000E+00  6.5000E-03  1.2000E+03
  EU154         7.4047E+04  8.5148E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.2261E-06  0.0000E+00  1.0000E-02  1.2000E+03
  EU155         4.3362E+04  7.5867E-01  1.4400E-06  0.0000E+00  1.4400E-06  1.0925E-06  0.0000E+00  1.6000E-02  1.2000E+03
  RA226         1.4053E+07  9.9915E-01  3.4500E-07  0.0000E+00  3.4500E-07  3.4471E-07  0.0000E+00  5.6000E+02  5.0000E+01
  TH230         7.0100E+08  9.9998E-01  2.1300E-07  0.0000E+00  2.1300E-07  2.1300E-07  0.0000E+00  2.3000E-02  1.2000E+03
  TH232         1.2300E+14  1.0000E+00  2.5200E-08  0.0000E+00  2.5200E-08  2.5200E-08  0.0000E+00  1.2000E-07  1.2000E+03
  U235          6.2200E+12  1.0000E+00  9.6000E-08  0.0000E+00  9.6000E-08  9.6000E-08  0.0000E+00  2.4000E-06  2.0000E+00
  U238          3.9120E+13  1.0000E+00  2.1300E-06  0.0000E+00  2.1300E-06  2.1300E-06  0.0000E+00  3.8000E-07  2.0000E+00
  NP237         1.8737E+10  1.0000E+00  1.3800E-10  0.0000E+00  1.3800E-10  1.3800E-10  0.0000E+00  8.0000E-04  7.0100E+01
  PU238         7.5412E+05  9.8428E-01  9.6000E-07  0.0000E+00  9.6000E-07  9.4490E-07  0.0000E+00  6.3000E-04  2.0000E+02
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 PU239      2.4100E+04  9.9994E-01  1.2700E-07  0.0000E+00  1.2910E-07  1.2294E-07  0.0000E+00  2.2100E-06  2.0000E+02
 PU240      5.7610E+07  9.9974E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0000E-07  0.0000E+00  6.3000E-06  2.0000E+02
 PU241      1.1504E+05  9.9101E-01  4.5500E-05  0.0000E+00  4.2500E-05  4.1650E-05  0.0000E+00  4.1000E-05  2.0000E+02
 PU242      4.7801E+09  1.0000E+00  7.2000E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.4000E-07  2.0000E+02
 AM241      5.7502E+00  9.9685E-01  5.0000E-08  0.0000E+00  5.0000E-08  6.7716E-10  0.0000E+00  4.1000E-05  7.0000E+01
 AM242      1.0014E+01  0.0000E+00  4.4000E-09  0.0000E+00  4.4000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
 AM243      6.9698E+07  9.9983E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2984E-09  0.0000E+00  7.1000E-02  7.0000E+01
 CM242      3.9100E+03  8.0940E-02  7.5000E-06  0.0000E+00  7.5000E-06  3.5245E-07  0.0000E+00  4.0000E-02  7.0000E+01
 CM243      2.6240E+05  9.5545E-01  1.8000E-09  0.0000E+00  1.8000E-09  1.7194E-09  0.0000E+00  6.2000E-04  7.0000E+01
 CM244      1.5540E+05  9.2631E-01  5.7000E-07  0.0000E+00  5.7000E-07  5.2800E-07  0.0000E+00  4.7000E-04  7.0000E+01


     DD          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  2.0110E-02  8.3248E-15  4.5132E-19  0.0000E+00  9.6561E-08  5.8377E-14  1.0224E-15  2.5211E-12  3.0085E-14  5.9416E-12
 5.0000E-01  0.0000E+00  6.1328E-13  4.7212E-16  0.0000E+00  5.0784E-07  5.4869E-12  8.3120E-14  1.5654E-10  1.9605E-12  3.6899E-10
 1.0000E+00  0.0000E+00  1.3748E-11  1.1379E-14  0.0000E+00  1.3743E-06  1.4853E-10  1.5173E-12  3.7874E-09  4.7777E-11  8.9306E-09
 5.0000E+00  0.0000E+00  6.6205E-10  5.1129E-13  0.0000E+00  6.2124E-06  1.3428E-08  6.8174E-11  1.7132E-07  2.1763E-09  4.0403E-07
 1.0000E+01  0.0000E+00  4.0570E-08  3.1303E-11  0.0000E+00  3.8190E-05  1.2377E-06  4.1759E-09  1.0560E-05  1.3509E-07  2.4908E-05
 1.5000E+01  0.0000E+00  1.8515E-06  1.4288E-09  0.0000E+00  1.7514E-04  8.5049E-05  1.4949E-07  4.8515E-04  6.2512E-06  1.1447E-03
 2.0000E+01  0.0000E+00  2.9405E-05  2.2689E-08  0.0000E+00  2.8083E-04  2.0331E-03  3.0252E-06  7.7574E-03  1.0068E-04  1.8307E-02


     DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  6.5734E-15  2.6840E-05  0.0000E+00  2.5221E-17  6.7009E-06  0.0000E+00  1.2594E-09  0.0000E+00  7.6137E-08  1.3402E-06
 5.0000E-01  4.1510E-13  2.5393E-05  0.0000E+00  1.5926E-15  5.2427E-07  3.3714E-15  1.9533E-09  0.0000E+00  5.4569E-09  1.0485E-07
 1.0000E+00  9.9706E-12  1.2400E-05  0.0000E+00  3.8286E-14  0.0000E+00  2.5517E-13  1.8320E-09  0.0000E+00  1.5834E-20  0.0000E+00
 5.0000E+00  4.4835E-10  1.1638E-05  0.0000E+00  1.7202E-12  0.0000E+00  3.4380E-11  1.9726E-09  0.0000E+00  0.0000E+00  0.0000E+00
 1.0000E+01  2.7450E-08  1.4652E-05  0.0000E+00  1.0532E-10  0.0000E+00  6.3127E-09  3.6764E-09  0.0000E+00  0.0000E+00  4.3155E-18
 1.5000E+01  1.2527E-06  1.3815E-05  0.0000E+00  4.8064E-09  4.4188E-18  8.6395E-07  5.1224E-09  5.1788E-14  0.0000E+00  0.0000E+00
 2.0000E+01  1.9845E-05  4.6481E-06  0.0000E+00  7.6335E-08  3.7842E-18  4.1134E-05  2.5257E-09  2.4647E-05  9.6343E-22  3.4846E-18


     DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
    (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
 0.0000E+00  0.0000E+00  1.0277E-12  2.7193E-08  8.8195E-15  0.0000E+00  0.0000E+00  0.0000E+00  1.6975E-14  0.0000E+00  0.0000E+00
 5.0000E-01  0.0000E+00  1.2596E-11  3.3140E-07  5.5693E-13  0.0000E+00  0.0000E+00  0.0000E+00  5.6710E-13  0.0000E+00  0.0000E+00
 1.0000E+00  0.0000E+00  6.1590E-11  1.0237E-06  1.3388E-11  0.0000E+00  0.0000E+00  0.0000E+00  6.8246E-12  0.0000E+00  0.0000E+00
 5.0000E+00  0.0000E+00  5.0266E-10  1.1758E-05  6.0155E-10  4.3339E-15  4.1212E-14  3.0726E-14  1.5342E-10  7.1428E-15  6.8517E-16
 1.0000E+01  0.0000E+00  6.9986E-09  1.0198E-04  3.6829E-08  3.2539E-12  3.0676E-11  2.7335E-11  4.6987E-09  5.3379E-12  6.0602E-13
 1.5000E+01  0.0000E+00  6.4917E-08  1.0702E-03  1.6804E-06  1.8059E-09  1.7927E-08  1.5172E-08  1.0727E-07  2.9603E-09  3.4308E-10
 2.0000E+01  1.9691E-03  2.1001E-07  5.3846E-03  2.0694E-05  3.4869E-07  3.2878E-06  2.9294E-06  8.5276E-07  5.7113E-07  6.7577E-08
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      THE TIME IS  4.5090E+04 HOURS, WHICH IS        4 YEAR(S), 12 MONTH(S), AND   0 DAY(S) FROM THE BEGINNING.

 DELT  IS 5.0000E+00 AND  DETT  IS 1.0000E+02

 NORMAL RAIN

    SOIL       CUM RAIN     WATER IN    CUM EVAPO-     CUM WATER    BALANCE
    FLUX       AND FLOOD     COLUMN        TRANS      OFF BOTTOM   % OF CUMS
 6.0000E-04   1.9910E+01   2.2356E+00  -2.9770E-02   1.9497E+01  -1.9442E-02

     DD          WTSOLD       VOLWAT       ANCLD          WA           RAS           W             H             H.            U
    (FT)           GM           ML          CI            CI            CI
 0.0000E+00   1.2035E+04   3.5343E+02   2.7883E-04   2.7227E-04   6.5580E-06   4.9925E-02   6.4268E-03  -4.1196E+03   3.4000E-03
 5.0000E-01   2.4069E+04   7.0687E+02   3.0234E-06   4.5665E-08   3.5781E-06   4.9925E-02   6.3047E-03  -4.1142E+03  -2.9348E-02
 1.0000E+00   1.0841E+05   3.1810E+03   7.4792E-06   4.0954E-08   7.4383E-06   4.9926E-02   6.3051E-03  -4.1187E+03  -2.8123E-02
 5.0000E+00   2.1003E+05   6.3627E+03   3.9933E-05   8.0911E-08   3.9852E-05   4.9932E-02   6.3049E-03  -4.1152E+03  -2.8123E-02
 1.0000E+01   2.4069E+05   7.0707E+03   2.4523E-04   3.2074E-07   2.4491E-04   4.9940E-02   6.3051E-03  -4.1107E+03  -2.8122E-02
 1.5000E+01   2.4069E+05   7.0717E+03   1.5944E-03   1.3165E-06   1.5930E-03   4.9947E-02   6.3049E-03  -4.1062E+03  -2.8122E-02
 2.0000E+01   3.0194E+05   1.0604E+04   1.0111E-02   4.4576E-06   1.0106E-02   4.9954E-02   6.3050E-03  -4.1019E+03  -2.8123E-02
 3.0000E+01   4.4139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9964E-02   6.3150E-03  -4.0928E+03  -2.8123E-02
 4.0000E+01   4.4139E+05   1.4154E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9988E-02   9.5600E-02  -4.0839E+03  -2.2727E-01
 5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   9.5600E-02  -4.0740E+03   3.4003E-03

 NUCLIDE          HALF         DECAY       ORIGINAL     REMAINING       ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
  NAME            LIFE         FACTOR       AMOUNT      ON SURFACE    COL-AN DEC     COLUMN       BOTTOM
 H3            1.0821E+05   7.5597E-01   3.6000E-04   0.0000E+00   3.6000E-04   2.7215E-04   0.0000E+00   2.6000E+04   0.0000E+00
 C14           5.0171E+07   9.9940E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1393E-05   0.0000E+00   2.2000E+04   1.0000E+02
 S35           2.1079E+03   0.0000E+00   2.5800E-06   0.0000E+00   2.5800E-06   0.0000E+00   0.0000E+00   9.1000E+02   1.0000E+02
 CR51          6.6442E+02   0.0000E+00   1.2900E-03   0.0000E+00   1.2900E-03   0.0000E+00   0.0000E+00   5.3000E+04   1.0000E+01
 MN54          7.7137E+03   1.9750E-02   7.5000E-04   0.0000E+00   7.5000E-04   1.4812E-05   0.0000E+00   6.6000E+07   1.0000E+01
 FE55          2.3621E+04   2.7759E-01   1.2900E-03   0.0000E+00   1.2900E-03   3.5864E-04   0.0000E+00   3.5000E+03   1.5000E+02
 CO58          1.7101E+03   0.0000E+00   1.2900E-03   0.0000E+00   1.2900E-03   0.0000E+00   0.0000E+00   4.8000E+03   1.0000E+02
 CO60          4.5990E+04   5.1775E-01   3.9000E-03   0.0000E+00   3.9000E-03   2.0192E-03   0.0000E+00   1.7000E+03   1.0000E+02
 NI59          7.0100E+08   9.9996E-01   3.9000E-05   0.0000E+00   3.9000E-05   3.8998E-05   0.0000E+00   1.1000E-01   1.0000E+02
 NI63          8.0620E+05   9.6315E-01   7.2000E-03   0.0000E+00   7.2000E-03   6.9346E-03   0.0000E+00   8.2000E+01   1.0000E+02
 ZN65          5.8372E+03   5.5929E-03   6.0000E-05   0.0000E+00   6.0000E-05   3.3557E-07   0.0000E+00   7.0000E+07   1.0000E+02
 SR90          2.4982E+05   8.8588E-01   1.4400E-05   0.0000E+00   1.4400E-05   1.2757E-05   0.0000E+00   2.1000E+02   2.0000E+00
 NB94          3.0353E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+03   1.0000E+02
 ZR95          1.5727E+03   0.0000E+00   6.0000E-05   0.0000E+00   6.0000E-05   0.0000E+00   0.0000E+00   1.8000E+08   1.0000E+02
 TC99          1.8565E+09   9.9998E-01   9.6000E-08   0.0000E+00   9.6000E-08   9.5994E-08   0.0000E+00   1.4000E+02   1.0000E-01
 RU106         8.8494E+03   3.2682E-02   6.0000E-05   0.0000E+00   6.0000E-05   1.9609E-06   0.0000E+00   1.9000E+08   3.0000E+02
 SN121         1.4054E+03   0.0000E+00   1.5000E-05   0.0000E+00   1.5000E-05   0.0000E+00   0.0000E+00   5.1000E+04   3.0000E+00
 SB125         2.4243E+04   2.8745E-01   1.5000E-05   0.0000E+00   1.5000E-05   4.3118E-06   0.0000E+00   3.0000E+03   3.0000E+09
 I125          1.4355E+03   0.0000E+00   4.5000E-06   0.0000E+00   4.5000E-06   0.0000E+00   0.0000E+00   7.6000E+05   1.0000E-01
 I129          1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9200E-08   0.0000E+00   7.2000E-02   1.0000E-01
 CS134         1.7961E+04   1.8535E-01   1.4400E-03   0.0000E+00   1.4400E-03   2.6690E-04   0.0000E+00   1.9000E+03   2.0000E+19
 CS135         2.6348E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-03   2.0000E+01
 CS137         2.6280E+05   8.9119E-01   2.5800E-03   0.0000E+00   2.5800E-03   2.2993E-03   0.0000E+00   1.3000E+02   2.0000E+01
 CE144         6.8133E+03   1.1758E-02   6.0000E-05   0.0000E+00   6.0000E-05   7.0547E-07   0.0000E+00   1.8000E+06   1.0000E+02
 EU152         1.1742E+05   7.7274E-01   1.4400E-07   0.0000E+00   1.4400E-07   1.1127E-07   0.0000E+00   6.5000E-03   1.2000E+03
 EU154         7.4887E+04   6.6603E-01   1.4400E-06   0.0000E+00   1.4400E-06   9.5908E-07   0.0000E+00   1.0000E-02   1.2000E+03
 EU155         4.3362E+04   4.9750E-01   1.4400E-06   0.0000E+00   1.4400E-06   7.1641E-07   0.0000E+00   1.8000E-02   1.2000E+03
 RA226         1.4053E+07   9.9785E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4426E-07   0.0000E+00   5.6000E+02   5.0000E+01
 TH230         7.0100E+08   9.9996E-01   2.1300E-07   0.0000E+00   2.1300E-07   2.1299E-07   0.0000E+00   2.3000E-02   1.2000E+03
 TH232         1.2364E+14   1.0000E+00   2.5200E-08   0.0000E+00   2.5200E-08   2.5200E-08   0.0000E+00   1.2000E-07   1.2000E+03
 U235          6.2200E+12   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   2.4000E-06   2.0000E+00
 U238          3.9420E+13   1.0000E+00   2.1300E-06   0.0000E+00   2.1300E-06   2.1300E-06   0.0000E+00   3.8000E-07   2.0000E+00
 NP237         1.8737E+10   1.0000E+00   1.3800E-10   0.0000E+00   1.3800E-10   1.3800E-10   0.0000E+00   8.6000E-04   7.6000E+01
 PU238         7.5412E+05   9.6065E-01   9.6000E-07   0.0000E+00   9.6000E-07   9.2223E-07   0.0000E+00   6.3000E-04   2.0000E+02
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PU239     2.1000E+04  9.9988E-01  1.2900E-07  0.0000E+00  1.2900E-07  1.2900E-07  0.0000E+00  2.2000E-06  2.0000E+02
PU240     5.7016E+07  9.9948E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0080E-07  0.0000E+00  8.3000E-06  2.0000E+02
PU241     1.1503E+05  7.0966E-01  4.9500E-05  0.0000E+00  4.9500E-05  3.4040E-05  0.0000E+00  8.1000E-03  2.0000E+02
PU242     4.7861E+09  9.9990E-01  7.2000E-10  0.0000E+00  7.2000E-10  7.2000E-10  0.0000E+00  1.0000E-07  2.0000E+02
AM241     3.7942E+06  9.9205E-01  9.6000E-08  0.0000E+00  9.6000E-08  8.9285E-08  0.0000E+00  4.1000E-05  7.0000E+01
AM242     1.6018E+01  0.0000E+00  4.8000E-09  0.0000E+00  4.8000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
AM243     6.4698E+07  9.4957E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2473E-09  0.0000E+00  7.1000E-02  7.0000E+01
CM242     3.0160E+03  4.3065E-04  7.5000E-06  0.0000E+00  7.5000E-06  3.2074E-09  0.0000E+00  4.0000E-02  7.0000E+01
CM243     2.6280E+05  8.9119E-01  1.8000E-09  0.0000E+00  1.8000E-09  1.0041E-09  0.0000E+00  6.2000E-04  7.0000E+01
CM244     1.5846E+05  8.2408E-01  5.7000E-07  0.0000E+00  5.7000E-07  4.0073E-07  0.0000E+00  9.7000E-04  7.0000E+01

    DD          H3          C14         S35         CR51        MN54        FE55        CO58        CO60        NI59        NI63
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  2.1968E-02  2.2854E-12  0.0000E+00  0.0000E+00  1.2308E-06  6.4657E-12  0.0000E+00  3.9902E-10  7.5781E-12  1.3696E-09
5.0000E-01  0.0000E+00  5.0117E-11  0.0000E+00  0.0000E+00  2.0607E-06  2.3934E-10  0.0000E+00  9.8171E-09  1.8700E-10  3.3699E-08
1.0000E+00  0.0000E+00  5.4407E-10  0.0000E+00  0.0000E+00  2.0088E-06  3.4441E-09  0.0000E+00  9.5431E-08  1.0229E-09  3.2762E-07
5.0000E+00  0.0000E+00  9.8182E-09  0.0000E+00  0.0000E+00  4.7604E-06  9.4416E-08  0.0000E+00  1.7267E-06  3.3077E-08  5.9208E-06
1.0000E+01  0.0000E+00  2.4041E-07  0.0000E+00  0.0000E+00  1.1730E-05  3.4720E-06  0.0000E+00  4.2394E-05  8.1438E-07  1.4557E-04
1.5000E+01  0.0000E+00  4.3728E-06  0.0000E+00  0.0000E+00  2.1518E-05  9.4453E-05  0.0000E+00  7.7315E-04  1.4898E-05  2.6550E-03
2.0000E+01  0.0000E+00  2.7574E-05  0.0000E+00  0.0000E+00  1.3837E-05  8.7741E-04  0.0000E+00  4.8884E-03  9.4440E-05  1.6780E-02

    DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SN126       SB125       I125        I129
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  6.7354E-14  4.4951E-04  0.0000E+00  0.0000E+00  7.3751E-06  4.3410E-16  0.0000E+00  0.0000E+00  0.0000E+00  1.4750E-06
5.0000E-01  1.6529E-12  1.0313E-04  0.0000E+00  0.0000E+00  1.8707E-07  4.2830E-14  0.0000E+00  0.0000E+00  0.0000E+00  3.7419E-08
1.0000E+00  1.6025E-11  1.7299E-05  0.0000E+00  0.0000E+00  0.0000E+00  1.2449E-12  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E+00  2.8919E-10  6.8448E-06  0.0000E+00  0.0000E+00  0.0000E+00  6.7338E-11  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
1.0000E+01  7.0811E-09  3.3747E-06  0.0000E+00  0.0000E+00  0.0000E+00  4.9443E-09  0.0000E+00  0.0000E+00  0.0000E+00  4.3155E-18
1.5000E+01  1.2880E-07  1.2880E-06  0.0000E+00  0.0000E+00  4.4187E-18  2.0903E-07  0.0000E+00  6.1464E-14  0.0000E+00  0.0000E+00
2.0000E+01  8.1216E-07  1.8049E-07  0.0000E+00  0.0000E+00  3.7841E-18  5.0931E-06  0.0000E+00  1.1602E-05  0.0000E+00  3.4846E-18

    DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  0.0000E+00  1.9684E-10  4.7864E-06  1.4160E-13  0.0000E+00  0.0000E+00  0.0000E+00  4.0041E-12  0.0000E+00  0.0000E+00
5.0000E-01  0.0000E+00  9.1984E-10  2.2295E-05  3.4749E-12  0.0000E+00  0.0000E+00  0.0000E+00  4.8479E-11  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  1.8037E-09  4.1016E-05  3.3690E-11  0.0000E+00  2.0500E-15  1.5314E-15  2.3541E-10  0.0000E+00  0.0000E+00
5.0000E+00  0.0000E+00  6.5788E-09  1.5864E-04  6.0795E-10  6.0389E-14  5.2925E-13  3.6984E-13  2.1267E-09  1.1548E-13  1.3273E-14
1.0000E+01  0.0000E+00  3.2485E-08  7.8119E-04  1.4887E-08  1.7824E-11  1.5361E-10  1.1075E-10  2.6056E-08  3.4137E-11  3.9743E-12
1.5000E+01  0.0000E+00  1.1927E-07  2.6603E-03  2.7077E-07  3.9085E-09  3.3688E-08  2.5163E-08  2.3718E-07  7.8835E-09  8.7832E-10
2.0000E+01  7.1814E-04  1.5258E-07  3.0491E-03  1.7074E-06  2.9679E-07  2.5580E-06  1.9108E-06  7.4945E-07  5.6808E-07  6.7217E-08
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     THE TIME IS  8.7600E+04 HOURS, WHICH IS        10 YEAR(S),  0 MONTH(S), AND  0 DAY(S) FROM THE BEGINNING.

DELT  IS 5.0000E+00 AND  DETT  IS 1.0000E+02

NORMAL RAIN

   SOIL      CUM RAIN    WATER IN   CUM EVAPO-   CUM WATER    BALANCE
   FLUX     AND FLOOD     COLUMN      TRANS     OFF BOTTOM  % OF CUMS
6.0000E-04  3.9621E+01  2.2356E+00 -5.9050E-02  3.9792E+01 -2.0148E-02

     DP          WTSOLD       VOLWAT       RNCLD         RAW          RAS           H            D            H            W
    (FT)           G?           ML           CI           CI           CI
0.0000E+00   1.2035E+04   3.5343E+02   2.1909E-04   2.0561E-08   1.3483E-05   4.9925E-02   6.8267E-03  -4.1196E+03   3.4000E-03
5.0000E-01   2.4069E+04   7.0687E+02   1.1059E-05   4.1447E-08   1.1009E-05   4.9924E-02   6.3047E-03  -4.1192E+03  -2.9503E-02
1.0000E+00   1.0831E+05   3.1810E+03   4.1179E-05   6.1528E-08   4.1112E-05   4.9925E-02   6.3051E-03  -4.1187E+03  -2.8123E-02
5.0000E+00   2.1663E+05   6.3627E+03   1.5837E-04   2.2038E-07   1.5815E-04   4.9932E-02   6.3050E-03  -4.1151E+03  -2.8122E-02
1.0000E+01   2.4069E+05   7.0707E+03   5.5050E-04   6.5484E-07   5.4992E-04   4.9940E-02   6.3050E-03  -4.1107E+03  -2.8121E-02
1.5000E+01   2.4069E+05   7.0717E+03   2.0819E-03   1.4750E-06   2.0804E-03   4.9947E-02   6.3050E-03  -4.1062E+03  -2.8121E-02
2.0000E+01   3.0104E+05   1.0609E+04   7.1561E-03   2.9002E-06   7.1535E-03   4.9954E-02   6.3050E-03  -4.1018E+03  -2.8121E-02
3.0000E+01   4.8139E+05   1.4150E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9969E-02   6.3150E-03  -4.0929E+03  -2.8121E-02
4.0000E+01   4.8139E+05   1.4158E+04   0.0000E+00   0.0000E+00   0.0000E+00   4.9980E-02   9.5600E-02  -4.0834E+03  -2.2725E-01
5.0000E+01   2.4069E+05   1.4159E+04   0.0000E+00   0.0000E+00   0.0000E+00   1.0000E-01   9.5600E-02  -4.0740E+03   3.4003E-03

NUCLIDE         HALF         DECAY      ORIGINAL     REMAINING     ENTERED     AMOUNT IN    AMOUNT OFF   SOLUBILITY   KD BASALT
 NAME           LIFE         FACTOR      AMOUNT     ON SURFACE   COL-AND DEC    COLUMN        BOTTOM
H3           1.0821E+05   5.7059E-01   3.6000E-04   0.0000E+00   3.6000E-04   2.0541E-04   0.0000E+00   2.0000E+04   0.0000E+00
C14          5.0171E+07   9.9879E-01   1.1400E-05   0.0000E+00   1.1400E-05   1.1388E-05   0.0000E+00   2.2000E+04   1.0000E+02
S35          2.1079E+03   0.0000E+00   2.5800E-06   0.0000E+00   2.5800E-06   0.0000E+00   0.0000E+00   9.1000E+02   1.0000E+02
CR51         6.6492E+02   0.0000E+00   1.2900E-03   0.0000E+00   1.2900E-03   0.0000E+00   0.0000E+00   5.3000E+09   1.0000E+01
MN54         7.7137E+03   3.0157E-04   7.5000E-04   0.0000E+00   7.5000E-04   2.9618E-07   0.0000E+00   6.6000E+07   1.0000E+01
FE55         2.3621E+04   7.6505E-02   1.2900E-03   0.0000E+00   1.2900E-03   9.8691E-05   0.0000E+00   3.5000E+03   1.5000E+02
CO58         1.7101E+03   0.0000E+00   1.2900E-03   0.0000E+00   1.2900E-03   0.0000E+00   0.0000E+00   4.8000E+04   1.0000E+02
CO60         4.5940E+04   2.6708E-01   3.9000E-03   0.0000E+00   3.9000E-03   1.0416E-03   0.0000E+00   1.7000E+05   1.0000E+02
NI59         7.0100E+08   9.9941E-01   3.9000E-05   0.0000E+00   3.9000E-05   3.8947E-05   0.0000E+00   1.1000E-01   1.0000E+02
NI63         8.0020E+05   9.2745E-01   7.2000E-03   0.0000E+00   7.2000E-03   6.6777E-03   0.0000E+00   8.2000E+01   1.0000E+02
ZN65         5.8372E+03   3.0383E-05   6.0000E-05   0.0000E+00   6.0000E-05   1.8230E-09   0.0000E+00   7.0000E+07   1.0000E+02
SR90         2.4082E+05   7.8428E-01   1.4400E-05   0.0000E+00   1.4400E-05   1.1293E-05   0.0000E+00   2.1000E+02   2.0000E+00
NB94         3.0353E-01   0.0000E+00   4.2000E-07   0.0000E+00   4.2000E-07   0.0000E+00   0.0000E+00   1.6000E+05   1.0000E+02
ZR95         1.5727E+03   0.0000E+00   6.0000E-05   0.0000E+00   6.0000E-05   0.0000E+00   0.0000E+00   1.8000E+08   1.0000E+02
TC99         1.8505E+09   9.9997E-01   9.6000E-08   0.0000E+00   9.6000E-08   9.5997E-08   0.0000E+00   1.4000E+02   1.0000E-01
RU106        8.8498E+03   1.0478E-03   6.0000E-05   0.0000E+00   6.0000E-05   6.2886E-08   0.0000E+00   1.9000E+04   3.0000E+02
SB124        1.4054E+03   0.0000E+00   1.5000E-05   0.0000E+00   1.5000E-05   0.0000E+00   0.0000E+00   5.1000E+04   3.0000E+00
SB125        2.4283E+04   8.2053E-02   1.5000E-05   0.0000E+00   1.5000E-05   1.2308E-06   0.0000E+00   3.0000E+05   3.0000E+09
I125         1.4385E+03   0.0000E+00   4.5000E-06   0.0000E+00   4.5000E-06   0.0000E+00   0.0000E+00   7.6000E+06   1.0000E-01
I129         1.4916E+11   1.0000E+00   1.9200E-08   0.0000E+00   1.9200E-08   1.9200E-08   0.0000E+00   7.2000E-02   1.0000E-01
CS134        1.7961E+04   3.4030E-02   1.4400E-03   0.0000E+00   1.4400E-03   4.9003E-05   0.0000E+00   1.9000E+05   2.0000E+19
CS135        2.6394E+10   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   1.7000E-05   2.0000E+01
CS137        2.6280E+05   7.9371E-01   2.5900E-03   0.0000E+00   2.5900E-03   2.0471E-03   0.0000E+00   1.3900E+02   2.0000E+01
CE144        6.8133E+03   1.3485E-04   6.0000E-05   0.0000E+00   6.0000E-05   8.0907E-09   0.0000E+00   1.8000E+06   1.0000E+02
EU152        1.1742E+05   5.9626E-01   1.4400E-07   0.0000E+00   1.4400E-07   8.5861E-08   0.0000E+00   6.5000E-05   1.2000E+03
EU154        7.0087E+04   4.4258E-01   1.4400E-06   0.0000E+00   1.4400E-06   6.3732E-07   0.0000E+00   1.0000E-02   1.2000E+03
EU155        4.3362E+04   2.4654E-01   1.4400E-06   0.0000E+00   1.4400E-06   3.5502E-07   0.0000E+00   1.8000E-02   1.2000E+03
RA226        1.4053E+07   9.9569E-01   3.4500E-07   0.0000E+00   3.4500E-07   3.4351E-07   0.0000E+00   5.6000E+02   5.0000E+01
TH230        7.0100E+09   9.9991E-01   2.1300E-07   0.0000E+00   2.1300E-07   2.1298E-07   0.0000E+00   2.3000E-02   1.2000E+03
TH232        1.2364E+14   1.0000E+00   2.5200E-08   0.0000E+00   2.5200E-08   2.5200E-08   0.0000E+00   1.2000E-07   1.2000E+03
U235         6.2200E+12   1.0000E+00   9.6000E-08   0.0000E+00   9.6000E-08   9.6000E-08   0.0000E+00   2.4000E-05   2.0000E+00
U238         3.9426E+13   1.0000E+00   2.1300E-06   0.0000E+00   2.1300E-06   2.1300E-06   0.0000E+00   3.8000E-07   2.0000E+00
NP237        1.8737E+10   1.0000E+00   1.3800E-10   0.0000E+00   1.3800E-10   1.3800E-10   0.0000E+00   8.0000E-04   7.0000E+01
PU238        7.5412E+05   9.2269E-01   9.6000E-07   0.0000E+00   9.6000E-07   8.8579E-07   0.0000E+00   6.3000E-04   2.0000E+02
```

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PU239     2.1900E+04  9.9971E-01  1.2900E-07  0.0000E+00  1.2900E-07  1.2896E-07  0.0000E+00  2.2000E-09  2.0000E+02
PU240     5.7610E+07  9.9895E-01  2.0100E-07  0.0000E+00  2.0100E-07  2.0072E-07  0.0000E+00  6.3000E-06  2.0000E+02
PU241     1.1563E+05  5.9151E-01  4.7500E-05  0.0000E+00  4.7500E-05  2.9280E-05  0.0000E+00  4.1000E-03  2.0000E+02
PU242     4.7731E+09  9.9990E-01  7.2000E-10  0.0000E+00  7.2000E-10  7.1993E-10  0.0000E+00  1.4000E-07  2.0000E+02
AM241     3.7442E+06  9.6812E-01  9.0000E-08  0.0000E+00  9.0000E-08  8.8571E-08  0.0000E+00  4.1000E-05  7.0000E+01
AM242     1.6014E+01  0.0000E+00  4.4000E-09  0.0000E+00  4.4000E-09  0.0000E+00  0.0000E+00  1.2000E-04  7.0000E+01
AM243     6.9698E+07  9.9913E-01  6.3000E-09  0.0000E+00  6.3000E-09  6.2945E-09  0.0000E+00  7.1000E-02  7.0000E+01
CM242     3.9160E+03  0.0000E+00  7.5000E-06  0.0000E+00  7.5000E-06  0.0000E+00  0.0000E+00  4.0000E-02  7.0000E+01
CM243     2.0260E+09  7.9371E-01  1.4200E-09  0.0000E+00  1.4200E-09  1.1287E-09  0.0000E+00  6.2000E-04  7.0000E+01
CM244     1.5698E+05  6.7837E-01  5.7000E-07  0.0000E+00  5.7000E-07  3.8667E-07  0.0000E+00  9.7000E-04  7.0000E+01


    DD          H3          C14         S35         CA51        MN54        FE55        CO58        CO60        NI59        NI63
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  1.0561E-02  1.3253E-10  0.0000E+00  0.0000E+00  5.8930E-07  1.0722E-10  0.0000E+00  1.2031E-08  4.4677E-10  7.7110E-08
5.0000E-01  0.0000E+00  1.6158E-09  0.0000E+00  0.0000E+00  5.5199E-07  1.9803E-09  0.0000E+00  1.4688E-07  5.4621E-09  9.4141E-07
1.0000E+00  0.0000E+00  7.8538E-09  0.0000E+00  0.0000E+00  2.6921E-07  1.4435E-08  0.0000E+00  7.1484E-07  2.6621E-08  4.5819E-06
5.0000E+00  0.0000E+00  7.0920E-08  0.0000E+00  0.0000E+00  2.4791E-07  1.9553E-07  0.0000E+00  8.4637E-06  2.4105E-07  4.1433E-05
1.0000E+01  0.0000E+00  8.6738E-07  0.0000E+00  0.0000E+00  3.0622E-07  3.5888E-06  0.0000E+00  7.9159E-05  2.9562E-06  5.0744E-04
1.5000E+01  0.0000E+00  7.8712E-06  0.0000E+00  0.0000E+00  2.8145E-07  4.0860E-05  0.0000E+00  7.1931E-04  2.6900E-05  4.6112E-03
2.0000E+01  0.0000E+00  2.4766E-05  0.0000E+00  0.0000E+00  9.2025E-08  2.5946E-04  0.0000E+00  2.2663E-03  8.4871E-05  1.4529E-02


    DD          ZN65        SR90        NB94        ZR95        TC99        RU106       SB124       SB125       I125        I129
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  2.1220E-14  7.7307E-04  0.0000E+00  0.0000E+00  7.3756E-06  1.1905E-15  0.0000E+00  0.0000E+00  0.0000E+00  1.4752E-06
5.0000E-01  2.5870E-13  6.2161E-05  0.0000E+00  0.0000E+00  1.9673E-07  4.2695E-14  0.0000E+00  0.0000E+00  0.0000E+00  3.7347E-08
1.0000E+00  1.2574E-12  1.0239E-06  0.0000E+00  0.0000E+00  0.0000E+00  6.2961E-13  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
5.0000E+00  1.1355E-11  2.0543E-07  0.0000E+00  0.0000E+00  0.0000E+00  1.6789E-11  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
1.0000E+01  1.3887E-10  5.3132E-08  0.0000E+00  0.0000E+00  0.0000E+00  6.1553E-10  0.0000E+00  0.0000E+00  0.0000E+00  4.3155E-18
1.5000E+01  1.2602E-09  1.0441E-08  0.0000E+00  0.0000E+00  4.4188E-18  1.0740E-08  0.0000E+00  3.5230E-14  0.0000E+00  0.0000E+00
2.0000E+01  3.9652E-09  7.9998E-10  0.0000E+00  0.0000E+00  3.7681E-18  1.5758E-07  0.0000E+00  3.3117E-08  0.0000E+00  3.4846E-18


    DD          CS134       CS135       CS137       CE144       EU152       EU154       EU155       RA226       TH230       TH232
   (FT)       MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM      MCI/GM
0.0000E+00  0.0000E+00  7.8888E-09  1.6945E-04  9.4176E-14  0.0000E+00  0.0000E+00  0.0000E+00  2.1022E-10  0.0000E+00  0.0000E+00
5.0000E-01  0.0000E+00  1.7235E-08  3.0961E-04  1.1492E-12  0.0000E+00  0.0000E+00  0.0000E+00  1.2466E-09  0.0000E+00  0.0000E+00
1.0000E+00  0.0000E+00  1.6924E-08  3.6240E-04  5.5805E-12  2.8052E-15  2.5529E-14  1.4271E-14  3.0373E-09  7.6431E-15  0.0000E+00
5.0000E+00  0.0000E+00  3.0918E-08  6.6125E-04  5.0393E-11  3.7541E-13  2.7864E-12  1.5522E-12  1.3744E-08  9.3162E-13  1.0894E-13
1.0000E+01  0.0000E+00  7.6170E-08  1.0260E-03  6.1633E-10  5.5190E-11  4.0969E-10  2.2820E-10  8.4139E-08  1.3694E-10  1.6074E-11
1.5000E+01  0.0000E+00  1.3950E-07  2.9753E-03  5.5931E-09  6.0178E-09  4.4609E-08  2.4883E-08  3.8237E-07  1.4930E-08  1.7595E-09
2.0000E+01  1.3165E-04  8.9467E-08  1.4961E-03  1.7598E-08  2.2698E-07  1.6848E-06  4.3952E-07  6.0404E-07  5.6302E-07  6.6622E-08

    EXPOSURE TIME IS    0.8760E+05HOURS
```

```
                                          EROSION OUTPUT
        WE HAVE  23 BLOCKS OF TIME (HOURS)

 0.1000E+05  0.8261E+05  0.8362E+05  0.8439E+05  0.8477E+05  0.8504E+05
 0.8549E+05  0.8568E+05  0.8578E+05  0.8601E+05  0.8621E+05  0.8640E+05
 0.8659E+05  0.8665E+05  0.8684E+05  0.8688E+05  0.8693E+05  0.8701E+05
 0.8712E+05  0.8712E+05  0.8722E+05  0.8737E+05  0.8760E+05

    EXPOSURE TIME IS   0.8760E+05HOURS
```

```
                                                  AQUIFER OUTPUT

          WE HAVE   7 BLOCKS OF TIME (HOURS)

 0.1000E+05  0.8660E+05  0.8693E+05  0.8712E+05  0.8722E+05  0.8737E+05
 0.8760E+05
```

```
                                    DOSE OUTPUT (MREM)
                                    FOR PATH 1
                                       TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 2

                          CUMULATIVE POPULATION DOSE       0.00E+00
                     DIRECT EXPOSURE DOSE(REM/PERSON)      0.00E+00

              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


    RADIONUCLIDE
    H3          0.00E+00     C14        0.00E+00
    S35         0.00E+00     CR51       0.00E+00
    MN54        0.00E+00     FE55       0.00E+00
    CO58        0.00E+00     CO60       0.00E+00
    NI59        0.00E+00     NI63       0.00E+00
    ZN65        0.00E+00     SR90       0.00E+00
    NB94        0.00E+00     ZR95       0.00E+00
    TC99        0.00E+00     RU106      0.00E+00
    SN124       0.00E+00     SB125      0.00E+00
    I125        0.00E+00     I129       0.00E+00
    CS134       0.00E+00     CS135      0.00E+00
    CS137       0.00E+00     CE144      0.00E+00
    EU152       0.00E+00     EU154      0.00E+00
    EU155       0.00E+00     RA226      0.00E+00
    TH230       0.00E+00     TH232      0.00E+00
    U235        0.00E+00     U238       0.00E+00
    NP237       0.00E+00     PU238      0.00E+00
    PU239       0.00E+00     PU240      0.00E+00
    PU241       0.00E+00     PU242      0.00E+00
    AM241       0.00E+00     AM242      0.00E+00
    AM243       0.00E+00     CM242      0.00E+00
    CM243       0.00E+00     CM244      0.00E+00


    DISTANCE(M)
     1600.      0.00E+00      3200.     0.00E+00
     4800.      0.00E+00      6400.     0.00E+00
     8000.      0.00E+00     10000.     0.00E+00
    12000.      0.00E+00


    PATH
CLOUD SHINE          0.00E+00 GROUND SHINE        0.00E+00
D. INHALATION        0.00E+00 R. INHALATION       0.00E+00
WATER INGESTION      0.00E+00 L. V. INGESTION     0.00E+00
ROOT INGESTION       0.00E+00 MILK INGESTION      0.00E+00
MEAT INGESTION       0.00E+00


    ORGAN
  WHOLE BODY      0.00E+00    BONE           0.00E+00
  LIVER           0.00E+00    KIDNEY         0.00E+00
  GONAD           0.00E+00    LUNG           0.00E+00
  G.I.TRACT       0.00E+00    THYROID        0.00E+00
  SKIN            0.00E+00
```

Moore Business Forms, Inc.

```
AGE GROUP
 CHILD     0.00E+00       TEEN      0.00E+00
 ADULT     0.00E+00
```

```
                                                      TOTAL DOSE OUTPUT (REM)
                                                         TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 2

                           CUMULATIVE POPULATION DOSE        0.00E+00
                      DIRECT EXPOSURE DOSE(REM/PERSON)       0.00E+00

                    TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
                    DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


   RADIONUCLIDE
   H3          0.00E+00      C14         0.00E+00
   S35         0.00E+00      CR51        0.00E+00
   MN54        0.00E+00      FE55        0.00E+00
   CO58        0.00E+00      CO60        0.00E+00
   NI59        0.00E+00      NI63        0.00E+00
   ZN65        0.00E+00      SR90        0.00E+00
   NB94        0.00E+00      ZR95        0.00E+00
   TC99        0.00E+00      RU106       0.00E+00
   SB124       0.00E+00      SB125       0.00E+00
   I125        0.00E+00      I129        0.00E+00
   CS134       0.00E+00      CS135       0.00E+00
   CS137       0.00E+00      CE144       0.00E+00
   EU152       0.00E+00      EU154       0.00E+00
   EU155       0.00E+00      RA226       0.00E+00
   TH230       0.00E+00      TH232       0.00E+00
   U235        0.00E+00      U238        0.00E+00
   NP237       0.00E+00      PU238       0.00E+00
   PU239       0.00E+00      PU240       0.00E+00
   PU241       0.00E+00      PU242       0.00E+00
   AM241       0.00E+00      AM242       0.00E+00
   AM243       0.00E+00      CM242       0.00E+00
   CM243       0.00E+00      CM244       0.00E+00


  DISTANCE(M)
    1600.      0.00E+00       3200.     0.00E+00
    4800.      0.00E+00       6400.     0.00E+00
    8000.      0.00E+00      10000.     0.00E+00
   12000.      0.00E+00


   PATH
CLOUD SHINE        0.00E+00 GROUND SHINE       0.00E+00
D. INHALATION      0.00E+00 R. INHALATION      0.00E+00
WATER INGESTION    0.00E+00 L. V. INGESTION    0.00E+00
ROOT INGESTION     0.00E+00 MILK INGESTION     0.00E+00
BEEF INGESTION     0.00E+00


    ORGAN
  WHOLE BODY     0.00E+00    BONE          0.00E+00
  LIVER          0.00E+00    KIDNEY        0.00E+00
  GONAD          0.00E+00    LUNG          0.00E+00
  G.I.TRACT      0.00E+00    THYROID       0.00E+00
  SKIN           0.00E+00
```

```
     AGE GROUP
      CHILD     0.00E+00      TEEN     0.00E+00
      ADULT     0.00E+00
```

CASE 9

```
  TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 2

SCENARIO NUMBER :112

INTRUSION OF SURFACE WATER, WATER SEEPAGE TO WATER
 TABLE THROUG BURIED WASTES.

          INVENTORY :WS-6

           PATH          RELEASE
                         FRACTION
  1        9100            0.1E+00
           9  UNSATURATED ZONE WATER TRANSPORT
           1  AQUIFER TRANSPORT
```

```
        PATH NUMBER:  1
     NUCLIDE      AMOUNT
                  CI/M**3

       H3       1.200E-02
       C14      3.800E-04
       S35      8.600E-05
       CR51     4.300E-02
       MN54     2.500E-02
       FE55     4.300E-02
       CO58     4.300E-02
       CO60     1.300E-01
       NI59     1.300E-03
       NI63     2.400E-01
       ZN65     2.000E-03
       SR90     4.800E-04
       NB94     1.400E-05
       ZR95     2.000E-03
       TC99     3.200E-06
       RU106    2.000E-03
       SB124    5.000E-04
       SB125    5.000E-04
       I125     1.500E-04
       I129     6.400E-07
       CS134    4.800E-02
       CS135    3.200E-06
       CS137    8.600E-02
       CE144    2.000E-03
       EU152    4.800E-06
       EU154    4.800E-05
       EU155    4.800E-05
       RA226    1.150E-05
       TH230    7.100E-06
       TH232    8.400E-07
       U235     3.200E-06
       U238     7.100E-05
       NP237    4.600E-09
       PU238    3.200E-05
       PU239    4.300E-06
       PU240    6.700E-06
       PU241    1.650E-03
       PU242    2.400E-08
       AM241    3.000E-06
       AM242    1.600E-07
       AM243    2.100E-07
       CM242    2.500E-04
       CM243    6.000E-08
       CM244    1.900E-05

WILL RUN PROBLEM THROUGH UNSAT FOR   0.8760E+05  HOURS

EXPOSURE TIME IS   0.8760E+05HOURS
```

```
                         DOSE OUTPUT (MREM)
                         FOR PATH 1
                           TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 2

                   CUMULATIVE POPULATION DOSE         0.00E+00
               DIRECT EXPOSURE DOSE(REM/PERSON)       0.00E+00

           TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
           DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

    RADIONUCLIDE
    H3          0.00E+00     C14       0.00E+00
    S35         0.00E+00     CR51      0.00E+00
    MN54        0.00E+00     FE55      0.00E+00
    CO58        0.00E+00     CO60      0.00E+00
    NI59        0.00E+00     NI63      0.00E+00
    ZN65        0.00E+00     SR90      0.00E+00
    NB94        0.00E+00     ZR95      0.00E+00
    TC99        0.00E+00     RU106     0.00E+00
    SB124       0.00E+00     SB125     0.00E+00
    I125        0.00E+00     I129      0.00E+00
    CS134       0.00E+00     CS135     0.00E+00
    CS137       0.00E+00     CE144     0.00E+00
    EU152       0.00E+00     EU154     0.00E+00
    EU155       0.00E+00     RA226     0.00E+00
    TH230       0.00E+00     TH232     0.00E+00
    U235        0.00E+00     U238      0.00E+00
    NP237       0.00E+00     PU238     0.00E+00
    PU239       0.00E+00     PU240     0.00E+00
    PU241       0.00E+00     PU242     0.00E+00
    AM241       0.00E+00     AM242     0.00E+00
    AM243       0.00E+00     CM242     0.00E+00
    CM243       0.00E+00     CM244     0.00E+00

    DISTANCE(M)
     1600.      0.00E+00      3200.    0.00E+00
     4800.      0.00E+00      6400.    0.00E+00
     8000.      0.00E+00     10000.    0.00E+00
    12000.      0.00E+00

     PATH
  CLOUD SHINE          0.00E+00 GROUND SHINE        0.00E+00
  D. INHALATION        0.00E+00 R. INHALATION       0.00E+00
  WATER INGESTION      0.00E+00 L. V. INGESTION     0.00E+00
  ROOT INGESTION       0.00E+00 MILK INGESTION      0.00E+00
  BEEF INGESTION       0.00E+00

     ORGAN
   WHOLE BODY   0.00E+00   BONE        0.00E+00
   LIVER        0.00E+00   KIDNEY      0.00E+00
   GONAD        0.00E+00   LUNG        0.00E+00
   G.I.TRACT    0.00E+00   THYROID     0.00E+00
```

```
AGE GROUP
 CHILD    0.00E+00     TEEN     0.00E+00
 ADULT    0.00E+00
```

```
                              TOTAL DOSE OUTPUT (MREM)
                               TEST CASES FOR REPORT NUMBER 4 11/6/80 SITE 2

                    CUMULATIVE POPULATION DOSE        0.00E+00
                DIRECT EXPOSURE DOSE(REM/PERSON)      0.00E+00


              TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
              DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


    RADIONUCLIDE
    H3          0.00E+00     C14        0.00E+00
    S35         0.00E+00     CR51       0.00E+00
    MN54        0.00E+00     FE55       0.00E+00
    CO58        0.00E+00     CO60       0.00E+00
    NI59        0.00E+00     NI63       0.00E+00
    ZN65        0.00E+00     SR90       0.00E+00
    NB94        0.00E+00     ZR95       0.00E+00
    TC99        0.00E+00     RU106      0.00E+00
    SB124       0.00E+00     SB125      0.00E+00
    I125        0.00E+00     I129       0.00E+00
    CS134       0.00E+00     CS135      0.00E+00
    CS137       0.00E+00     CE144      0.00E+00
    EU152       0.00E+00     EU154      0.00E+00
    EU155       0.00E+00     RA226      0.00E+00
    TH230       0.00E+00     TH232      0.00E+00
    U235        0.00E+00     U238       0.00E+00
    NP237       0.00E+00     PU238      0.00E+00
    PU239       0.00E+00     PU240      0.00E+00
    PU241       0.00E+00     PU242      0.00E+00
    AM241       0.00E+00     AM242      0.00E+00
    AM243       0.00E+00     CM242      0.00E+00
    CM243       0.00E+00     CM244      0.00E+00

    DISTANCE(M)
     1600.      0.00E+00      3200.     0.00E+00
     4800.      0.00E+00      6400.     0.00E+00
     8000.      0.00E+00     10000.     0.00E+00
    12000.      0.00E+00

    PATH
 CLOUD SHINE        0.00E+00 GROUND SHINE       0.00E+00
 D. INHALATION      0.00E+00 R. INHALATIUN      0.00E+00
 WATER INGESTION    0.00E+00 L. V. INGESTION    0.00E+00
 ROOT INGESTION     0.00E+00 MILK INGESTION     0.00E+00
 BEEF INGESTION     0.00E+00

    ORGAN
   WHOLE BODY    0.00E+00    BONE          0.00E+00
   LIVER         0.00E+00    KIDNEY        0.00E+00
   GONAD         0.00E+00    LUNG          0.00E+00
   G.I.TRACT     0.00E+00    THYROID       0.00E+00
   SKIN          0.00E+00
```

```
AGE GROUP
 CHILD    0.00E+00      TEEN      0.00E+00
 ADULT    0.00E+00
```

CASE 10

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    TEST CASES FOR REPORT NUMBER 1 11/26/79

  SCENARIO NUMBER 113

  FIRE ERUPTS IN THE TRUCK TRANSPORTING WASTES ON
  PUBLIC HIGHWAY (E.G. AS A RESULT OF AN ACCIDENT).
  FIRE IS ALLOWED TO BURN-OUT.

  -      INVENTORY INS-2

         PATH           RELEASE
                        FRACTION
1        3000            0.1E+01
         3  WASTE CONTACT (SHINE)
2        2000            0.2E-01
         2  ATMOSPHERIC TRANSPORT
```

```
                 PATH NUMBER   1
           NUCLIDE      AMOUNT
                       CI/M**3

            CR51     1.820E-01
            CO58     1.820E-01
            FE55     1.820E-01
            ZN65     9.100E-03
            ZR95     9.100E-03
            RU106    9.100E-03
            SB124    9.100E-03
            SB125    9.100E-03
            EU152    1.820E-05
            EU154    1.820E-04
            EU155    1.820E-04
            SR90     1.820E-03
            CS137    3.770E-01
            MN54     9.100E-02
            CS134    2.000E-01
            H3       2.210E-02
            C14      1.040E-03
            NI59     2.600E-04
            TC99     2.600E-04
            I129     1.300E-05
            CS135    1.300E-05
            NP237    1.300E-05
            PU238    1.690E-05
            PU239    1.820E-05
            PU240    2.600E-05
            PU241    7.020E-03
            PU242    7.280E-03
            AM241    1.690E-04
            AM242    5.200E-05
            AM243    1.300E-05
            CM242    1.170E-04
            CM243    1.300E-05
            CM244    7.800E-05

   EXPOSURE TIME IS    0.5000E+00HOURS

   VOLUME OF PACKAGE IS    0.4000E+02 CUBIC METERS
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```
                              DOSE OUTPUT (AREA4)
                                  FOR PATH 1
                                     TEST CASES FOR REPORT NUMBER 4 11/6/80

                   CUMULATIVE POPULATION DOSE            0.00E+00
              DIRECT EXPOSURE DOSE(REM/PERSON)           1.42E-08

         TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
         DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

 RADIONUCLIDE
 CR51       0.00E+00      CO58       0.00E+00
 FE55       0.00E+00      ZN65       0.00E+00
 ZR95       0.00E+00      RU106      0.00E+00
 SB124      0.00E+00      SB125      0.00E+00
 EU152      0.00E+00      EU154      0.00E+00
 EU155      0.00E+00      SR90       0.00E+00
 CS137      0.00E+00      MN54       0.00E+00
 CS134      0.00E+00      H3         0.00E+00
 C14        0.00E+00      NI59       0.00E+00
 TC99       0.00E+00      I129       0.00E+00
 CS135      0.00E+00      NP237      0.00E+00
 PU238      0.00E+00      PU239      0.00E+00
 PU240      0.00E+00      PU241      0.00E+00
 PU242      0.00E+00      AM241      0.00E+00
 AM242      0.00E+00      AM243      0.00E+00
 CM242      0.00E+00      CM243     -0.00E+00
 CM244      0.00E+00


 DISTANCE(M)
     0.     0.00E+00


 PATH
CLOUD SHINE          0.00E+00 GROUND SHINE        0.00E+00
D. INHALATION        0.00E+00 R. INHALATION       0.00E+00
WATER INGESTION      0.00E+00 L. V. INGESTION     0.00E+00
ROOT INGESTION       0.00E+00 MILK INGESTION      0.00E+00
BEEF INGESTION       0.00E+00


  ORGAN
 WHOLE BODY     0.00E+00    BONE           0.00E+00
 LIVER          0.00E+00    KIDNEY         0.00E+00
 GONAD          0.00E+00    LUNG           0.00E+00
 G.I.TRACT      0.00E+00    THYROID        0.00E+00
 SKIN           0.00E+00


  AGE GROUP
   CHILD       0.00E+00        TEEN      0.00E+00
   ADULT       0.00E+00
```

```
          PATH NUMBER   2
   NUCLIDE       AMOUNT
                 CI/M**3

    CR51      3.640E-03
    CO58      3.640E-03
    FE55      3.640E-03
    ZN65      1.820E-04
    ZR95      1.820E-04
    RU106     1.820E-04
    SB124     1.820E-04
    SB125     1.820E-04
    EU152     3.640E-07
    EU154     3.640E-06
    EU155     3.640E-06
    SR90      3.640E-05
    CS137     7.540E-03
    MN54      1.820E-03
    CS134     4.160E-03
    H3        4.420E-04
    C14       2.080E-05
    NI59      5.200E-06
    TC99      5.200E-06
    I129      2.600E-07
    CS135     2.600E-07
    NP237     2.600E-07
    PU238     3.360E-07
    PU239     3.640E-07
    PU240     5.200E-07
    PU241     1.040E-05
    PU242     1.350E-09
    AM241     3.380E-06
    AM242     1.040E-06
    AM243     2.600E-07
    CM242     2.340E-06
    CM243     2.600E-07
    CM244     1.560E-06

EXPOSURE TIME IS   0.5000E+00HOURS
```

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                         DOSE OUTPUT (MREM)
                         FOR PATH 2
                            TEST CASES FOR REPORT NUMBER 4 11/6/80

             CUMULATIVE POPULATION DOSE          1.20E+02
        DIRECT EXPOSURE DOSE(REM/PERSON)         0.00E+00


          TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
          DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

   RADIONUCLIDE
   CR51       3.58E-03     CO58      2.60E-01
   FE55       1.44E-02     ZN65      2.53E-02
   ZR95       5.92E-03     RU106     7.60E-04
   SB124      1.51E-02     SB125     2.11E-02
   EU152      4.62E-06     EU154     1.32E-03
   EU155      7.39E-05     SR90      3.80E-01
   CS137      4.61E+00     CE144     2.15E-01
   CS134      5.32E+00     H3        2.09E-04
   C14        1.16E-04     NI59      7.07E-05
   TC99       4.31E-06     I129      5.02E-04
   CS135      1.34E-04     NP237     6.09E-01
   PU238      5.22E-03     PU239     1.82E-02
   PU240      1.36E-02     PU241     4.10E-02
   PU242      1.07E+02     AM241     5.40E-02
   AM242      2.58E-08     AM243     6.39E-03
   CM242      2.50E-02     CM243     6.45E-02
   CM244      3.08E-01


   DISTANCE(M)
    1600.     2.80E+00      3200.    2.68E+01
    4800.     4.00E+01      6400.    1.49E+01
    8000.     1.60E+01     10000.    8.23E+00
   12000.     1.05E+01


   PATH
 CLOUD SHINE         4.46E-04 GROUND SHINE        1.77E+00
 D. INHALATION       4.88E-01 R. INHALATION       1.08E+02
 WATER INGESTION     0.00E+00 L. V. INGESTION     7.54E+00
 ROOT INGESTION      4.14E-05 MILK INGESTION      1.34E+00
 BEEF INGESTION      4.26E-01


    ORGAN
  WHOLE BODY     1.20E+02    BONE           4.29E+03
  LIVER          6.00E+02    KIDNEY         4.59E+02
  GONAD          1.79E+01    LUNG           3.19E+02
  G.I.TRACT      3.86E+01    THYROID        1.88E+00
  SKIN           2.14E+01


    AGE GROUP
     CHILD     2.71E+01       TEEN     1.92E+01
     ADULT     7.31E+01
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                                        TOTAL DOSE OUTPUT (AAEP)
                                          TEST CASES FOR REPORT NUMBER 4 11/6/80

                       CUMULATIVE POPULATION DOSE        1.20E+02
                   DIRECT EXPOSURE DOSE(REM/PERSON)      1.92E-04


                TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL,
                DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.


    RADIONUCLIDE
    CR51        3.58E-03      CO58        2.64E-01
    FE55        1.40E-02      ZN65        2.53E-02
    ZR95        5.92E-03      RU106       7.60E-04
    SB124       1.51E-02      SB125       2.11E-02
    EU152       4.62E-06      EU154       1.32E-03
    EU155       7.34E-05      SR90        3.40E-01
    CS137       4.61E+00      MN54        2.15E-01
    CS134       5.32E+00      H3          2.88E-04
    C14         1.16E-04      NI59        7.87E-05
    TC99        4.31E-06      I129        5.02E-04
    CS135       1.34E-04      NP237       6.49E-01
    PU238       5.22E-03      PU239       1.82E-02
    PU240       1.36E-02      PU241       4.19E-02
    PU242       1.07E+02      AM241       5.49E-02
    AM242       2.58E-08      AM243       6.39E-03
    CM242       2.50E-02      CM243       6.45E-02
    CM244       3.08E-01


    DISTANCE(M)
     1600.      2.80E+00       3200.      2.63E+01
     4800.      4.00E+01       6400.      1.45E+01
     8000.      1.60E+01      10000.      8.83E+00
    12000.      1.05E+01


    PATH
 CLOUD SHINE          4.46E-04 GROUND SHINE        1.77E+00
 D. INHALATION        4.46E-01 R. INHALATION       1.08E+02
 WATER INGESTION      0.00E+00 L. V. INGESTION     7.54E+00
 ROOT INGESTION       4.14E-05 MILK INGESTION      1.34E+00
 BEEF INGESTION       4.26E-01


    ORGAN
  WHOLE BODY     1.20E+02    BONE           4.29E+03
  LIVER          6.08E+02    KIDNEY         4.58E+02
  GONAD          1.74E+00    LUNG           3.15E+02
  G.I.TRACT      3.88E+00    THYROID        1.88E+00
  SKIN           2.16E+01


    AGE GROUP
     CHILD      2.71E+01        TEEN      1.92E+01
     ADULT      7.31E+01
```

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USDA, [illegible] "[illegible] in the United States and Their [illegible]."

USDA, [illegible] Agricultural [illegible] "[illegible] of the United States and [illegible]."

[illegible], et al., [illegible]

[illegible]

[illegible]

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*[illegible] Commission, Washington, D.C. 20555, and/or the National Technical Information Service, Springfield, VA 22161.

**Available from the National Technical Information Service, Springfield, VA 22161 (only).

NRC FORM 335
(7 77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-1963, Vol. 2
SAI01380-652LJ

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
System Analysis of Shallow Land Burial
Volume 2: Technical Background

5. DATE REPORT COMPLETED
MONTH January
YEAR 1981

DATE REPORT ISSUED
MONTH March
YEAR 1981

6. *(Leave blank)*

7. AUTHOR(S)
D. Lester, D. Buckley, S. Donelson, V. Dura, et al.

8. *(Leave blank)*

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Science Applications, Inc.
P.O. Box 2351
La Jolla, CA 92038

10. PROJECT/TASK/WORK UNIT NO.

11. CONTRACT NO.
FIN No. B6428-9

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
U.S. Nuclear Regulatory Commission
Office of nuclear Material Safety and Safeguards
Division of Waste Management
Washington, DC 20555

13. TYPE OF REPORT
Technical Report

PERIOD COVERED *(Inclusive dates)*
9/26/79 - 1/23/81

14. *(Leave blank)*

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(200 words or less)*

A systems model for shallow land burial of low-level waste was assembled from existing models available in the nuclear industry. The model covers waste packaging, transportation, burial, and post burial activities. Subprograms were developed for unsaturated zone seepage, aquifer transport, wind erosion, and atmospheric transport. Release via available pathways are converted to population dose commitments using standard regulatory guide and ICRP Techniques. The system model starts with an initiating event selected from a list of scenarios from an event Tree Analysis Pathway Sequence, inventory, and release fraction for each scenario are available within a standard data base. The executive program which executes the system model calls subroutine in proper sequence and provides for the analysis of several hundred accident and scenario possiblilites.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES

22. PRICE
$

NRC FORM 335 (7 77)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

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